DEVELOPING ONE'S "TOOLBOX OF DESIGN" THROUGH THE LIVED EXPERIENCES OF WOMEN STUDENTS: ACADEMIC MAKERSPACES AS SITES FOR LEARNING

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DEVELOPING ONE'S "TOOLBOX OF DESIGN" THROUGH THE LIVED EXPERIENCES OF WOMEN STUDENTS: ACADEMIC MAKERSPACES AS SITES FOR LEARNING

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For the helpless

To see potential, beauty, and dignity

As makers.

To the first maker and to the next.

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SUMMARY

Many assert the potential for makerspaces to provide competency in design and promote learning, similar to the on-the-job learning that occurs in industry, yet evidence remains anecdotal. This research investigates how academic makerspaces at higher education institutions support design competencies and learning outcomes, particularly for women students. The following research questions guide this investigation: 1) what are the different types of design competencies and learning types that are reported by women in an academic makerspace, 2) how are women students' design and learning pathways into and through makerspaces developing, and 3) what are the implications for engineering design.

To answer the research questions, a multi-study research design was implemented. First, in Study One, woman makers participated in a three-part in-depth phenomenologically based interview series. The interviews were analyzed through a rigorous, iterative data analysis process that utilized open and axial coding methods to establish a typology of learning, a learning model, and the design and learning pathways. For Study Two, a targeted interview protocol on design learning was developed, executed with fifteen different women students, and analyzed in order to clarify, confirm, and expound upon the findings of Study One. Finally, higher education institutions are making large investments to install academic makerspaces. Therefore, in order to explicate implications for engineering design, Study Three employs an ancillary semi-structured qualitative interview protocol that was conducted with nine leaders of various nationwide makerspaces; the interviews were analyzed and juxtaposed with the findings of Study One

and Study Two. In turn, through implementing a multi-study research design, we define types of design competencies and learning types, model design and learning pathways, and articulate the significance of makerspaces in engineering design. Thereby, we discover that critical factors are influencing a woman student's involvement in the makerspace and that through the makerspace, women students have a notable expansion in the design competencies in their "toolbox of design." By exclusively examining women students' making experiences, we expose the value of academic makerspaces for developing one's "toolbox of design."

CHAPTER 1. INTRODUCTION

1.1 Motivation and Overview

As demonstrated by the number of makerspaces increasing over 14-fold in the last decade (Lou & Peek, 2016), there is a significant increase in the number of individuals, organizations, and universities advocating for the making experience. With this explosive growth, the value of making experiences and makerspaces in an educational setting must be ascertained (Blikstein & Krannich, 2013) and the challenges identified so as to justify the expensive investment into the building, staffing, and outfitting academic makerspaces. Challenges include but are not limited to: immense teacher preparation for integrating making into curricular activities, limited access to resources and technology, and the diverse and widespread experiences and interests of students (Hira et al., 2014).

It is speculated that the success of integrating the maker movement into universities and academia via makerspaces necessitates initiating a shift from an inflexible and traditional classroom-based approach to an environment ripe for creating, innovating, and collaborating (Donaldson, 2014; Papert & Harel, 1991b; Schön et al., 2014). It is believed that an educational system rooted in making has the potential to revolutionize thought on pedagogy and learning (Kurti et al., 2014b). Ultimately though, for such a revolution to take place, an understanding of the learning occurring in the academic makerspace is first needed, and second, an understanding of the best practices for creating an academic makerspace (see Figure 1). Together, the two efforts can provide valuable and practical insights towards makerspaces and pedagogical implications.

Figure 1: Two aspects of makerspaces to understand: that which goes into the makerspaces and the outcomes of the makerspace.

First, it is not enough to insist that students are learning in these spaces without empirical evidence. While advances have been made in studying the engineering design experiences in the classroom, challenges persist when trying to study the hands-on, real-world experiences occurring in academic makerspaces. Learning in makerspaces is challenging due to the very characteristics that make them unique, in that they are experiential, interactive, collaborative, self-paced, and problem-based (Halverson & Sheridan, 2014; Lande & Jordan, 2014; Litts, 2015). Some studies have looked into learning in makerspaces (Bieraugel & Neill, 2017; Bowler, 2014; Bowler & Champagne, 2016; Brady et al., 2014; Brahms & Wardrip, 2016; Brahms & Werner, 2013; Kafai et al., 2014; Litts, 2015; Peppler et al., 2016; Sheridan et al., 2014; Smith, 2017; Tomko et al., 2018a; Tomko et al., 2018b), but there remains little empirical evidence that shows the value of makerspaces for the educational and professional development of higher education students in STEM fields, especially for women students. In general, women are considered underrepresented in the maker movement, as seen by survey data that revealed that 81% of the maker demographic were male (Make/Intel, 2012). While there are unspoken societal rules that attach gender to the making and designing of things (Meyer, 2018), the apparent absence of women involved in the maker movement corresponds primarily to the fact that women are not included appropriately in the numbers. Failing to capture women in the number comes from the notion that the type of making women engage in is not acknowledged as ‘making,’ and that women tend to avoid makerspaces because they are typically dominated by men (Faulkner & McClard, 2014). At the university level, these factors can be detrimental to the overall education and academic rapport for women students. While universities continue to pour more dollars into the building and outfitting of makerspaces, it becomes more important to understand the impact of makerspaces on student learning, and it would be negligent to discount the value of understanding women students’ experiences.

Second, with the large investments into university makerspaces, understanding the impact that makerspaces have on student learning is one aspect, whereas we must also consider the large undertaking that comes with building and outfitting an academic makerspace. When considering the transition towards an educational system that focuses on making activities and makerspaces, numerous concerns and questions arise about funding sources, access plans, management models, and potential culture. Addressing these concerns when starting a university makerspace impacts the type of learning that students will employ. However, in the current efforts to identify best practices, the literature focuses on the outcomes versus the route towards success (Forest et al., 2014; Wilczynski, 2015). It remains difficult to attain success, even with the known factors, without having an understanding of how that success is achieved. Therefore, it becomes necessary to understand the beginning narratives of academic makerspaces targeted for engineering students at higher education institutions, as described from the perspective of those who played a formative role in the development of the university’s makerspace.

Therefore, juxtaposing beginning narrative of academic makerspaces and the women student narrative of learning and pathways into academic makerspaces can provide transformative insights that can truly revolutionize pedagogy, learning, and also initiatives for women in STEM.

1.2 Research Questions and Goals

We postulate that in order to understand the value and further articulate the challenges of makerspaces regarding women involvement, it is key that we investigate the learning experiences of women in these makerspaces through qualitative methodologies that allow for detailed accounts, specifically through using in-depth qualitative interviewing, semi-structured interviewing, and grounded theory techniques. While interviews have begun to illuminate the underlying beliefs for the gender gap of users in community makerspaces and the barriers to woman engagement (Lewis, 2015), using a multi-study interviewing approach provides an opportunity to elucidate the learning of these women students and the best practices of academic makerspaces. In turn, the overarching objective of this dissertation is to answer the following research question and meet the following research goal:

- **Research Question:** how are academic makerspaces supporting learning for women students?

- **Research Goal:** to qualitatively determine the value and challenges that academic makerspaces at a university setting have towards supporting the learning and acquisition of skills for women students.

1.2.1 Secondary Research Questions and Goals

The overarching research question and goal open the opportunity to understand and unveil the unique learning experiences with which women students engage through making activities and makerspaces. In order to narrow the scope, the main research question is further broken down into the smaller research questions and goals.

1.2.1.1 Secondary Research Question 1 (RQ1)

In efforts to understand the learning for women students, we seek to understand the types of learning by the following research question and goal:

- **Design and Learning (RQ1a)**: what are the different types of design competencies and learning types that are reported by women in an academic makerspace?

- **Research Goal**: to create a typology of learning that showcases the breadth and depth along with the learning outcomes and modes of learning that emerge from a woman's involvement in the academic makerspaces.

With the breadth and depth of learning, we can look towards how the conceptual understanding of how the women student gain competency in design and the other learning outcomes. This research question seeks to gain insights into how an individual develops expertise, acquires skills, and learns in the makerspace.

- **Design and Learning (RQ1b):** how are women students' design and learning competencies interacting and developing?

- **Research Goal:** to identify recurring themes in the women student narrative and to develop a learning model that illustrates the interaction between modes of learning and products of learning that emerged from the learning typology.

1.2.1.2 Secondary Research Question 2 (RQ2)

Because learning is contextualized by education precursors and sociocultural environments, the women students' learning and design experiences are impacted by their pathways into and through the makerspace. Thereby, to gain insights into how women students enter the space and what her journey looks like in gaining access to design and learning, we investigate the following research question and goal:

- **Pathways (RQ2):** how are women students' design and learning pathways into and through makerspaces developing?

- **Research Goal:** to extract themes for influential factors and barriers that impact a women student's journey or pathway through the making ecosystem and into a makerspace; to establish a model that shows the pathways of women students in the making ecosystem.

1.2.1.3 Secondary Research Question 3 (RQ3)

However, to generate practical insights for educational initiatives with academic makerspaces, we further must investigate the strategies and challenges that makerspace leaders encounter when developing and creating the academic makerspace, which leads into the following research question and goal:

- **Best Practices (RQ3a):** what are the best practices in the formation of an academic makerspace?

- **Research Goal:** to devise a record of shared strategies that various university makerspaces have used or encountered when in the process of developing a makerspace at their respective campuses.

The best practices coupled with the work on learning and pathways forward insights towards understanding the impact on engineering design through the following research question and goal:

- **Implications (RQ3b):** what are the implications for engineering design?

- **Research Goal:** to identify practical applications from the insights generated by the various interview studies of this dissertation towards engineering design.

1.3 Research Design Considerations

Since the research question seeks to capture *how* academic makerspaces are supporting women students learning, the research methodology needs to allow exploration of the lived experiences of women who are using these academic makerspaces. It is not enough to simply ask students what they are learning. Such an approach would lack the depth of inquiry that is necessary to answer the research questions. Therefore, gaining insight into lived experiences demands an in-depth qualitative approach, where exploration is possible. Because of the intriguing insights that emerged from previous ethnographic work on makerspaces (Tomko et al., 2017b; Tomko et al., 2017d; Tomko et al., 2017e), the initial plan for this work sought to draw from the strengths and characteristics of an ethnographic methodology, which would enable the study of processes *in situ* combined with the sensemaking activities that occur in in-depth interviewing (Tomko et al., 2017a).

However, capturing the lived experiences by drawing on the features of ethnographic methodologies requires a few preconditions: 1) established credibility and trust between the researcher and participants, and 2) negotiated access and availability to the participants over time and in a variety of making situations in a specific cultural context. In the first precondition, the researcher needs to establish trust with the participants. When a researcher asks to explore the culture of a space (where the study of culture is ethnography), people in the culture, in this case makerspace users, may have a suspicious and an off-putting attitude towards the researcher. Overcoming these participant concerns requires careful consideration and action on the researcher’s end, for the researcher does not want to risk distrust or resentment from the participant. For the second precondition, a thorough study of the participants over time would require nearly unconditional access to the participants and their work in the makerspace. The researcher would have to be available to meet with the participants at any time during the day, even potentially in the middle of the night, in order to maintain a consistent observation of the participant’s work. As such, the scope was narrowed to focus on highly involved women students, and these preconditions are reconciled using the provided research design.

1.4 Research Design

To answer the research questions, a multi-study research design was implemented.

1.4.1 Study One

First, in Study One, woman makers participated in a three-part in-depth phenomenologically based interview series. The interviews were analyzed through a rigorous, iterative data analysis process that utilized open and axial coding methods to establish the design competencies, the learning types, and the design and learning pathways. Study One aims to elicit the lived experiences of women students who are highly involved in makerspaces. The purpose of Study One is to (1) articulate types of design competencies and learning types, (2) identify how design and learning pathways are developing, and (3) provide insight for implications for engineering design – used in conjunction with Study Three.

1.4.2 Study Two

For Study Two, a targeted interview protocol on learning, design, and pathways was developed, executed with different women students, and analyzed in order to clarify and confirm the findings of Study One. The purpose of Study Two is to (1) verify the types of design competencies and learning types derived in Study One, as an intermediary step towards survey development and (2) expound on the types of pathways into makerspaces. This is done through a targeted interview protocol and interviewing process with women students who participate in academic makerspaces.

1.4.3 Study Three

Finally, higher education institutions are making large investments to install academic makerspaces. Therefore, to explicate implications for engineering design, Study Three employed an ancillary semi-structured qualitative interview protocol that was conducted with nine leaders of various nationwide makerspaces; these interviews were analyzed for best practices and then juxtaposed with the findings of Study One and Study Two. The purpose of Study Three is to (1) identify best practices of university makerspaces and (2) generate implications for engineering design, once used in conjunction with the findings of Study One and Study Two.

1.5 Contributions

This dissertation is a multidisciplinary effort that forwards qualitative research methods in engineering design and engineering education. Overall, this dissertation provides the foundational empirical evidence for learning, pathways, and best practices of makerspaces while introducing and demonstrating the effectiveness of a qualitative methodology for engineering design.

1.5.1 Contribution 1: A Methodological Roadmap

The presentation and demonstration of an in-depth phenomenologically based interviewing approach for studying complex phenomenon and lived experiences in engineering design research endeavors.

The changing nature of engineering design engages knowledge from multiple domains and seeks methodologies that can allow for valuable insights into dynamic and complex phenomena. This dissertation forwards a qualitative methodology novel to engineering design research – phenomenologically based interviewing. This dissertation presents the qualitative methodology in the form of a roadmap for engineering design researchers. To demonstrate the methodology in practice, the methodology is then described in the context of studying how academic makerspaces support women student learning. This has the potential to capture the nuances of learning in a making environment via a reflexive interview format that aims to understand lived experiences of women students. This methodology is highly applicable to other areas of design research such as understanding how a team or company's design process has evolved over time, along with gaining insights into why the design process has changed and why individuals believe the process to be effective. As such, four secondary contributions are considered:

- **An adapted interviewing process that is approachable and applicable for engineering design research.**

- **A detailed description for engineering design researchers of the processes and considerations for establishing rigor and credibility when using qualitative research methods.**

- **A collection of the important qualitative considerations that should be included when implementing and presenting qualitative work in engineering design.**

- **The benefits of using the phenomenologically based interviewing approach for studying a phenomenon of interest in engineering design as a means to achieve rich datasets and insights.**

1.5.2 Contribution 2: Learning in Makerspaces

An in-depth understanding of the impact that makerspaces have on women student learning.

To date, there is little empirical evidence that shows the learning of students in makerspaces. Through investigating how university makerspaces support women students learning along with their engagement in engineering design, we articulate the types of learning (both modes of learning and products of learning) that women students engage in, the themes of learning and design that recur in women student narratives, and the interaction between the types of learning (represented by a learning model). As such, three secondary contributions are considered:

- **The first thorough investigation of the types of learning, both modes and products of learning, that women students experience in a university makerspace – resulting in a typology of learning that shows the breadth of competencies forwarded by a university makerspace.**
- **The establishment of themes that contribute to a woman's experience learning and understanding design as a result of being involved in a university makerspace.**
- **A representation for how the learning unfolds in the makerspace, illustrating how the different types of learning engage with each other and how design skills are developed.**

1.5.3 Contribution 3: Pathways in Makerspaces

The understanding of influential factors and barriers that impact women student pathways into a university makerspace through a making ecosystem – considerations of youth and current making experiences.

The prevalence of academic makerspaces on university campuses has generated interest in understanding how to engage engineering students in these makerspaces and how these makerspaces impact their learning and development. However, for students entering into a professional community of practice (COP), like the makerspace, there are many educational precursors surrounding their pathway, where a student's previous experiences can make their entry into the makerspace easier or harder. Understanding women students' pathways into a makerspace require investigating contextual factors and barriers that are not necessarily captured in a typical pathway model. As such, three secondary contributions are considered:

- **A compilation of recurring themes of women student narratives as they experience making in their youth and coming into the university makerspace.**
- **The representation of women pathways into a making ecosystem and the variety of influential factors/barriers that occur on their pathways.**
- **The continuation of the conversation on pathways and ecosystem models used in engineering education, but through implementing a qualitative methodology.**

1.5.4 Contribution 4: Best Practice for Makerspaces

The development of four major strategies or best practices that university makerspaces should consider when forming or changing a makerspace.

University makerspaces continue to grow in number, and we can learn from the failures and successes of those who have already worked to achieve successful makerspaces. To understand how success is achieved, it is necessary to understand the beginning narratives of engineering-based academic makerspaces at higher education institutions. Through asking questions regarding culture and origins, we were able to generate approachable insights for what individuals should consider as they seek to build or improve a makerspace.

1.5.5 Contribution 5: Implications for Engineering Design

The establishment of overarching practical implications for how the multi-study insights impact engineering design.

In the efforts to implement a multi-study research design, the analysis of the various interview data for different research question results in multiple sets of themes. Together, these themes provide the opportunity to understand engineering design through multiple perspectives and ultimately showcase the ways that engineering design can support women students, learning, and pathways into the makerspace.

1.6 Considerations

This work acknowledges that the findings are not generalizable to the engineering design community. By using qualitative research methods, we embrace the notion of transferability, where the rich and descriptive data collected and analyzed in this dissertation provide transferable insights and findings for other researchers or individuals towards their respective research sites or communities. This dissertation aims to continue the conversation of qualitative research in engineering design, learning in makerspaces, pathways and ecosystems, best practices of makerspaces, and women in engineering/STEM.

1.7 Dissertation Layout

This dissertation is a multidisciplinary effort that engages various theoretical constructs and viewpoints. Following this introduction, we provide a review of the literature in chapter two. We start by addressing the question of what is a makerspace and how did a makerspace come into the university setting. We look to understand the initiatives and studies that emerged as a result of the university makerspaces. We narrow the viewpoint towards understanding specifically the learning that occurs in the makerspace, whether the learning theories that seemingly are at work in the makerspace, the potential learning that could come from the makerspace, or the studies that have looked at learning in the makerspace.

We continue the literature review by articulating the value of qualitative research methods and studies in engineering design that have used qualitative research methods. The literature review then gauges the diverse set of studies that have looked at student learning in engineering design and the benefits that can come from building physical models in engineering design – potentially similar to that of the building that occurs in makerspace. Then, the review concludes with literature on communities of practice and women in engineering.

After the literature review, chapter three dive into the methodology and methods of Study One and Study Two. We present the methodology in the form of a roadmap for engineering design researchers. As such, the roadmap is left ambiguous and is not connected to a specific research question. Therefore, after providing the extensive argument for the phenomenologically based interviewing process, we present an example of the methodology in practice – which is the Study One and Study Two of this dissertation.

Consequently, chapters four and five provide the findings that emerged from chapter three. Chapter four focuses on the learning in makerspaces, where we present the typology of learning, themes of learning, and a learning model. Chapter five presents the themes and a model in regards to the pathways of women students into and through the makerspace.

Taking a step back, chapter six engages the ancillary semi-structured interviews that aim to understand best practices of various university makerspaces. This chapter provides the methods used, makerspace profiles for the makerspace who participate in the study, and themes of best practices.

Finally, we wrap up with implications, limitations, and future work in chapter seven.

1.8 Summary

Through investigating how learning manifests in experiences of women students in academic makerspaces, we implemented a multi-study interviewing approach and grounded theory data analysis techniques in order to capture the lived experiences and the meaning of these experiences through emerging codes and themes. In turn, the multi-study research design includes:

1. integrating a reflexive in-depth interviewing approach in which women student participants articulate and reflect on their experiences making in an academic makerspace,
2. implementing a targeted semi-structure interviewing process that engages the learning, design competency, and pathways of highly involved women students, and
3. juxtaposing the data from the aforementioned interview processes with semi-structured interviews of leaders from various university makerspaces across the nation.

Through implementing a multi-study research design (see Figure 2), we created a roadmap for a methodological practice, defined types of design competencies and learning types, modeled design and learning pathways, and articulated the significance for makerspaces in engineering design. Thereby, we discovered the influential factors impacting a woman student's involvement in the makerspace, and that through the makerspace, women students have a notable expansion in the design competencies in their "toolbox of design." By focusing on the woman making experience, we expose the value of academic makerspaces for developing one's "toolbox of design."

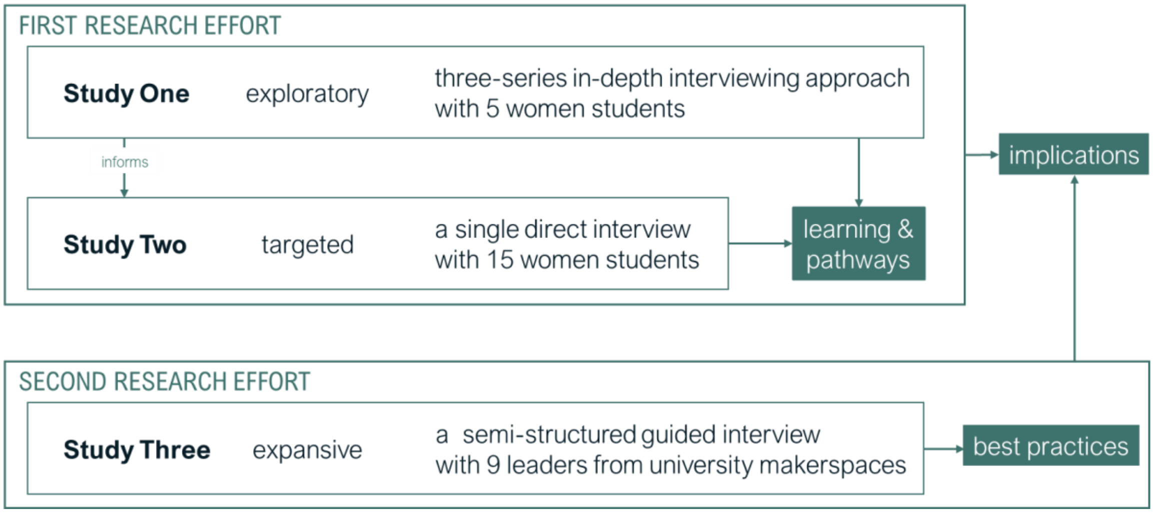

Figure 2: Overview of multi-study research design.

CHAPTER 2. BACKGROUND

In efforts to understand academic makerspaces at the university setting, we first seek to examine how the literature defines makerspaces. Subsequently, we aim to articulate how makerspaces developed a larger role in higher education schools and what research ensued as a means to understand the impact of these makerspaces, specific to best practices and learning. It becomes apparent that understanding makerspaces is challenging; as such, we describe the value of using qualitative research methods and how engineering design researchers harness the benefits of qualitative research and also study various phenomenon in engineering design. As a final point, we present how makerspaces engage communities of practices and women in engineering.

2.1 Makerspaces

2.1.1 Defining Makerspaces

Makerspaces are viewed as unique learning environments that center around the act of 'making' in all its' forms (Sheridan & Konopasky, 2016). What 'making' entails has been left purposefully ambiguous as per O'Connell (2015) so as to allow for all types of making, from sewing to machining, and to enable a variety of making activities to be considered as part of a maker community and its spaces. These spaces are seen to promote both the use and making of advanced technologies amidst the sharing of ideas and projects (Sheridan & Konopasky, 2016) and the sharing of tools, machines, and knowledge (Pernia-Espinoza et al., 2017). The collaboration, discovery, and innovation are seen as daily occurrences in a makerspace (Radniecki et al., 2016) where a community of people is provided access to an open space that allows innovative thought and resourcefulness via the tools, equipment, and environment (Halverson & Sheridan, 2014; Pernia-Espinoza et al., 2017). While seen by some as the next generation classroom (Colegrove, 2016), the makerspace seems to provide that bridge and fills the gap between universities and industry for the engineering, technical, science, and mathematical fields (Pernia-Espinoza et al., 2017).

While makerspaces are assumed to impact creativity, independence, and grit (Barron & Barron, 2016; Halverson & Sheridan, 2014), the argument stands that a makerspace environment fosters creative thinking through model building, arts, and visualization (Root-Bernstein & Root-Bernstein, 2013). Though it remains difficult to measure creativity (Blikstein et al., 2017), the claims for independence are supported via intrinsic motivation. Student engagement and motivation has been shown to increase when given the ability to make decisions through contextualization and personalization in instructional or training activities (Cordova & Lepper, 1996). While makerspaces offer this freedom to make decisions that are contextualized and personalized, they also are illustrated to unhinge the potential for the constructivist education theory since collaboration occurs in a teacher-learner style. Through a trial and error process, makerspaces are allowing students to engage in fabrication processes and design processes (Wilczynski & Adrezin, 2016). Not to mention, fifth graders who participate in makerspace activities are showing an increase in their grit (Steier & Young, 2016).

It is speculated that the success of integrating the maker movement into universities and academia via makerspaces necessitates initiating a shift from an inflexible and traditional classroom-based approach to an environment ripe for creating, innovating, and collaborating (Donaldson, 2014; Papert & Harel, 1991b; Schön et al., 2014). It is believed that an educational system rooted in making has the potential to revolutionize thought on pedagogy and learning (Kurti et al., 2014b). Ultimately though, for such a revolution to take place, an understanding of the learning occurring in the academic makerspace is first needed, which can further inform pedagogy. It is not enough to insist that students are learning in these spaces without empirical evidence.

2.1.2 Makerspaces, A History

The maker movement characterized the start of a new era where the do-it-yourself, or rather the do-it-with-others, mindset launched the collaboration and sharing of ideas within a community of makers. While no single event can be attributed to for the beginning of this era, the maker movement originated from a collaboration of events, ironically well-suited to the fact that the movement focuses on collaboration. The first catalyst that helped to launch the maker movement occurred in 2005 with the first publication of *Make: magazine* providing exclusive information and instruction on maker projects (Burke, 2014). In 2006, the advocates behind *Make: magazine* added to the movement by inviting makers of all ages and interests to join in attending the first annual Maker Faire. Henceforth, the maker movement was alive and active. The movement only grew stronger in 2007 with the introduction of the RepRap, the first desktop 3D printer that was open-source. Anderson (2012) ascribes the arrival of the RepRap as “another key milestone” since it led to the MakerBot, a desktop 3D printer for personal use.

Corresponding to the maker movement, spaces began evolving to harbor this maker mindset. Formed as a center in 2001, MIT’s Center for Bits and Atoms initiated efforts to gather tools across disciplines as a means to make and measure on the microscopic scale (Fab-Foundation, 2016). In this effort, the term “fab lab” was coined and had a large impact on the eventual evolution of makerspaces. While fab labs are identical in types of tools and materials, makerspaces are more diverse to suit community needs, yet both are designed to promote the use of technologies to support making and a shared mission. The combination of these fab labs and the maker movement helped to shift attitudes and change spaces. What were once shops that held tools and equipment for making, now were community-oriented spaces focused on making and collaboration. In February of 2016, Popular Science published an article showing the number of makerspaces having a 14-fold growth in one decade (Lou & Peek, 2016). In 2006, only a year after the launch of *Make: magazine,* the number of makerspaces worldwide was no more than 100 spaces collectively. In 2016, the collective worldwide number of makerspaces had reached nearly 1,400, with the U.S. having 483 spaces, Europe having 556 spaces, and then another 354 distributed throughout the rest of the world. While this article shows the worldwide growth of makerspaces, it is important to point out that the increase in the number of makerspaces included academic makerspaces; for in that time, there was also a movement to integrate and build makerspaces for educational purposes.

In education, new waves of thinking constantly drive changing pedagogies, learning strategies, and teaching initiatives, such as seen in Bloom’s taxonomy (Bloom et al., 1956; Krathwohl, 2002), experiential learning (Kolb, 1984), constructionism (Papert & Harel, 1991a) and situated learning (Lave & Wenger, 1991). Still, when it came to the maker movement, groundbreaking changes began to occur in the U.S. when the government launched the “Educate to Innovate” campaign in 2009 and then embraced the maker movement by hosting a Maker Faire at the White House in 2014. With President Obama advocating and supporting the increase in making activities and makerspaces, the U.S. libraries, museums, and schools began transforming their sites of learning into more hands-on and experiential realms of discovery.

2.1.3 Understanding Best Practices in Makerspaces

With this growth and interest in academic makerspaces, three initiatives formed toward sharing best practices and expanding academic makerspace access: The Maker Education Initiative, MakeSchools.org, and the Higher Education Makerspace Initiative. MakerEd, or Maker Education Initiative, was founded in 2012 to reach K-12 educators predominately in an effort to broaden exposure to making for all children (Maker-Education-Initiative, 2012) by creating a professional learning community of maker educators and database of curriculum and resources (Maker-Education-Initiative, 2012). MakeSchools.org, founded in 2014, serves as a clearinghouse where users can share their diverse definitions of making, showcase academic makers and makerspaces, and showcase making projects through a single web-portal (CMU, 2017a, 2017b). While this website does not distill best practices, it does allow users to begin to glean insight into how showcased academic makerspaces operate. Finally, as a venue to share insights, best practices, and research as well as to build community among the members affiliated with the growing number of university and K-12 makerspaces, the Higher Education Makerspace Initiative inaugurated the International Symposium on Academic Makerspaces (or ISAM) in 2016 (Culpepper & Wilczynski, 2016).

Still, there remains strikingly little empirical information about how to transform a makerspace from a room full of tools to a thriving and vibrant informal learning environment. When it comes to describing best practices or development processes of university makerspaces, the research falls primarily into the hands of two researchers who focus on engineering-based spaces: Wilczynski (Wilczynski, 2015; Wilczynski & Adrezin, 2016) and Forest (Forest et al., 2016; Forest et al., 2014). Toward identifying elements that are critical to an academic makerspace's success, Wilczynski (2015) reviewed seven large, successful makerspaces and identified six observed factors critical for success: (1) clearly defined mission, (2) proper staffing, (3) open architectural environment, (4) accessibility, (5) user training availability, and (6) maker community development. Beyond these six factors, Wilczynski and Adrezin (2016) elaborate on the importance of broader campus collaborations and self-promotion. Moreover, Forest et al. (2014) identify five critical factors to consider when developing academic makerspaces: (1) student engagement in makerspace operation, (2) reduction of entry barriers, (3) active faculty and staff support, (4) management of safety and liability, and (5) sustainable funding. Further, Forest et al. (2016) discuss the importance of understanding the optimal staff-to-user ratio and floor space-per-user ratio. Forest et al. (2016; 2014) in his research chooses instead to focus intensely on one space, the Invention Studio at Georgia Tech, while Wilczynski investigates seven well-known and well-established spaces – with one of these six makerspaces also being the Invention Studio. With a 14-fold growth in makerspaces in a decade, focusing on just seven well-established spaces does not necessarily provide a representative cross-section of experiences and principles for developing a thriving and vibrant learning academic makerspace community.

2.1.4 Studying Makerspaces

While numerous makerspaces have made way into universities and college campuses, researchers have implemented both quantitative and qualitative means to understand these unique and ripe environments. Amidst the studies that have sought to understand the makerspace or the impact on educational experiences, researchers have not only developed classifications of the different academic makerspaces, but also examined the culture, identity, and self-efficacy associated with these spaces (Hilton et al., 2018b; Morocz et al., 2015; Weiner et al., 2017; Wilczynski, 2017). For example, using artifact elicitation interviews – using artifacts such as photos or projects to evoke responses from participants, Oplinger et al. (2016) investigated the leadership roles of makers at United States Maker Faires and identified that makers demonstrated external leadership traits such as innovators, directors, and producers. In a similar vein, parents were found to take on roles of a designer, builder, cheerleader, or teacher when supporting their children in making activities at a museum makerspace (Dickens et al., 2016).

Former studies have examined a variety of aspects to makerspaces. In one vein, students who used a makerspace showed an improvement in communicating to non-engineers about engineering principles (Galaleldin et al., 2016). Other studies have evaluated the correlation between involvement in the makerspace to engineering design self-efficacy (Morocz et al., 2015); these studies show that voluntary involvement may lead to an increase in confidence and a decrease in anxiety, for engineering design tasks (Hilton et al., 2018b). Similarly, a mixed methods approach sought to understand the motivation of students and found that class projects and friends helped to encourage students to become more involved in the makerspace (Hilton et al., 2018c).

While research on maker education has started to explore culture, classify different types of spaces, and identify challenges in operation, the maker education research has lacked an understanding of learning outcomes despite the diverse knowledge and methods that are being used in engineering education (Weiner et al., 2018). Although makerspaces have been studied in a variety of ways, there remains a need to narrow the focus on learning, for the makerspace is demonstrating a diverse set of skills and attributes for students, yet no single study has tapered to look directly at all that is being learned, specific to engineering design, in the makerspace.

2.1.5 Learning in Makerspaces

2.1.5.1 Theories of Learning in Makerspaces

Makerspaces engage a type of learning that is social, hands-on, and contextualized, where constructs pertaining to traditional learning styles are incompatible for understanding the nuances of learning and knowledge-building within a makerspace. The type of learning within a makerspace invites the theoretical concepts associated with constructivism (Piaget, 1956), sociocultural development (Vygotsky, 1978), constructionism (Papert & Harel, 1991a) and situated learning (Lave & Wenger, 1991).

Constructivism is an epistemological stance that "describes knowledge not as truths to be transmitted or discovered, but as emergent, developmental, nonobjective, viable constructed explanations by humans engaged in meaning-making in cultural and social communities of discourse" (Fosnot, 2005, p. ix). Constructivist learning theories focus on how individuals make meaning and construct knowledge through experience (Piaget (1956)). Piaget's constructivism characterizes learning as a process where an individual's knowledge structures are confirmed or reconciled through experiences and interacting with one's environment (Kafai & Resnick, 1996; Piaget, 1956). An individual reconciles their knowledge structure when the information generated from experience fails to conform to the individual's existing framework; the reconfiguration does not occur in response to simply receiving information, rather there is an emphasis on the individual learning from an experience (Piaget, 1985). Embodied in the maker movement, the constructivist approach offers an opportunity to reform the educational system (Roffey, 2015)

Taking on a sociocultural perspective on learning, Vygotsky (1978) emphasizes that social interaction embedded in cultural practices are the means for learning to occur and knowledge to be constructed. An individual learns from being enculturated into a community and thereby acquires knowledge via directly interacting with the learning environment (Liu & Matthews, 2005); as such, learning is modeled as a situational and contextualized activity (Eggen & Kauchek, 1999; McInerney & McInerney, 2002; Woolfolk, 2001).

Similarly, constructionism focuses on how knowledge is constructed in context. However, constructionism is a theory for learning (Papert, 1996), where an individual elicits meaning and engages in learning through the act of making a meaningful, tangible artifact (Papert, 1993; Sheridan et al., 2014). Learning occurs in the process of transforming one's inner feelings and ideas into a physical medium that can be analyzed and admired (Litts, 2015; Papert, 1993); the making of the artifact helps to then inform, shape, and communicate ideas, as expressed within particular contexts (Ackermann, 2001). While constructionism may seemingly be simplified to learning through making, Papert and Harel (1991b) argue that the implication of this simplification negates the depth, richness, and versatility ingrained within the essence of constructionism, where learning-rich activities (e.g., building sandcastles, creating houses of Legos, or playing with a collection of cards) go beyond featuring a narrow skillset (Papert & Harel, 1991b). Centered around this expansive form of making, learning in constructionism offers a foundation for learning makerspaces, which are centered around the act of making in all its' forms (Sheridan & Konopasky, 2016). Even more so, Papert (1996) argues that there is an undoubtable link between the process for learning and the content from learning, reinforcing the need to study both how and what individuals are learning in the makerspace.

In situated learning, the emphasis shifts towards the context in which learning is occurring. Situated learning acknowledges that learning occurs from social interactions within the cultural constructs of authentic, real-world environments (Lave & Wenger, 1991). The acquisition of knowledge extends from the apprenticeship process that an individual undergoes in order to grow in experience and further membership into a community of practice. Prior to the onset of the concept of situated learning, 'apprenticeship' was without a theoretical foundation for meaning, impact on learning, nor differences from cognitive learning forms, despite the term being widely used in learning studies (Patel, 2017). With situated learning, apprenticeship extended beyond the simple master-apprenticeship mode into a well-formed theory that accentuates the mastery of knowledge through contextualized experiences (Patel, 2017). Similarly, makerspaces act as communities of practice by situating learning within a community of people who offer access to the tools, equipment, and an environment that provide a catalyst for innovative thought and resourcefulness (Halverson & Sheridan, 2014; Pernia-Espinoza et al., 2017).

2.1.5.2 Potential Benefits of Makerspaces for Learning

A variety of benefits have been suggested or expressed in regards to learning in makerspaces. Makerspaces are seen as an avenue to inspire creative, critical problem solving via individual's constructing and iterating hands-on designs, thereby providing a means to acquire specified 21st-century skills (Johnson et al., 2015). For example, makerspaces offer the opportunity to learn creative thinking from building models, creating art, and visualizing ideas (Root-Bernstein & Root-Bernstein, 2013). While drawing upon the natural human desire to make, makerspaces provide a means to inspire students in creativity, curiosity, independence, determination, and grit (Barron & Barron, 2016; Fleming, 2015; Halverson & Sheridan, 2014), where even fifth-graders who have had involvement in a makerspace have been shown to increase in their grit (Steier & Young, 2016). Not to mention that an individual's engagement and motivation will increase when given the opportunity to make contextualized and personalized decisions during instructional or training activities (Cordova & Lepper, 1996). When in the context of makerspaces, the act of making encourages an individual to become more active by taking control and responsibility for their own learning (Martinez & Stager, 2013, 2014). The inherent engaging and interdisciplinary nature of the makerspace empowers this agency in young people as a means to drive change in their communities and in a future not yet imagined (Davee et al., 2015; Johnson et al., 2015).

In a future not yet imagined lies the potential to revolutionize thought on pedagogy and learning by rooting the educational system in making (Kurti et al., 2014b). However, the success of a revolution where makerspaces facilitate the integration of the maker movement into the academic setting first requires a shift from the traditional lecture-style classroom towards a creative, innovative, and collaborative environment (Donaldson, 2014; Papert & Harel, 1991b; Schön et al., 2014). As a means for learning, makerspaces exhibit daily occurrences of collaboration, discovery, and innovation (Radniecki et al., 2016), where ideas, tools, machines, ideas, and knowledge are shared amidst the use of advanced technologies and the making of projects (Pernia-Espinoza et al., 2017; Sheridan & Konopasky, 2016). This type of collaborative learning environment is believed to be the next generation classroom (Colegrove, 2016), and is believed to be the ultimate bridge between university and industry, especially for STEM-related fields (Pernia-Espinoza et al., 2017). Perhaps even more revolutionary, the type of learning that makerspaces promote is seemingly compatible with the type of learning that is most needed by students with learning challenges (Waters, 2014).

2.1.5.3 Studies of Learning in Makerspaces

Studies that are specific to investigating the maker movement in education can be considered of three different forms: understanding makerspaces as learning environments, understanding makers as learners, or understanding making as a designed learning activity (Halverson & Sheridan, 2014; Peppler et al., 2016). Of interest in this work is understanding makerspaces as learning environments, where the research spans a variety of settings, including K-12 and higher education (Kafai et al., 2014; Peppler et al., 2016; Tomko et al., 2018a; Tomko et al., 2018b) libraries and museums (Bieraugel & Neill, 2017; Bowler, 2014; Bowler & Champagne, 2016; Brady et al., 2014; Brahms & Wardrip, 2016; Brahms & Werner, 2013; Litts, 2015; Sheridan et al., 2014), and mobile and online communities (Litts, 2015; Peppler et al., 2016; Smith, 2017). For example, in a children museum's makerspace, the learning and engagement of families and children are assisted by the presence and interaction with available tools and materials (Brahms & Werner, 2013). In investigations on K-12 and informal learning, individuals engaging in making activities are stated to have learned engineering, design, electronics, art, and computer programming (Halverson & Sheridan, 2014; Kafai et al., 2014). For studying academic library spaces at a mid-sized university, Bieraugel and Neill (2017) examined student perceptions on how different types of makerspaces supported certain behaviors and learning that would forward creativity and innovation; this study contextualized the survey in the form of Bloom's taxonomy and showcased how the students perceived learning to be supported in different makerspaces. Further, the engineering education literature on maker education does not make considerable use of learning science concepts and literature despite regularly alluding to the potential learning outcomes of maker education (Weiner et al., 2018).

Moreover, makerspaces can be characterized as experiential, interactive, collaborative, self-paced, and problem-based (Halverson & Sheridan, 2014; Lande & Jordan, 2014; Litts, 2015), where such characteristics are not compatible with controlled, quasi-experimental studies and call for the need for a methodology that suits these adaptive, complex, dynamic, and interactive environments. While prior work has investigated learning in makerspaces, there remains a need to gain insights into the learning that occurs towards the professional development of STEM students in higher education makerspaces.

2.2 Qualitative Research Characteristics

Qualitative research starts with an inquiry process of engaging the methodological traditions and assumptions, the researcher's paradigm, and the potential theoretical frameworks as a means to study a social or human problem (Creswell, 2007). Using qualitative research becomes appropriate when a complex, detailed understanding needs to be acquired or a problem needs to be explored (Creswell, 2007). However, there is an abundance of qualitative approaches in existence that have roots in philosophical traditions of varying epistemological, ontological, and methodological assumptions. Understanding these assumptions and philosophical traditions is necessary to the point of using approaches appropriately and within scope. For direction, numerous researchers have crafted classifications of qualitative approaches as a means to instruct researchers on the underlying methodological and philosophical assumptions associated with each approach; for quantitative researchers seeking to use qualitative methods, it is highly encouraged to understand the philosophical roots and assumptions associated with a qualitative approach of interest.

In conjunction with understanding methodological assumptions, qualitative research engages the researcher or research team's way of understanding reality, or their paradigm (Tracy, 2013). Paradigms fall within a spectrum: from positivist to interpretivist. While this is not addressed in quantitative research due to the consensus of objectivity, the researcher's paradigm is imperative to the methodology and data analysis processes used in qualitative research. Generally speaking, quantitative research takes on a positivist/post-positivist lens. In this lens, the research assumes a true reality that is tangible and fragmentable (Lincoln & Guba, 2000). Alternatively, the assumption of objectivity falters in the social realm, where human behavior lacks the same rule-based ontology found in physics, chemistry, etc. To rectify, the interpretive lens posits that knowledge and reality are constructed, communicated, and mediated (Tracy, 2013). This is particularly relevant when individual views of the same situation or phenomenon are different. Ultimately, with qualitative research, the lens that the researcher uses impacts the final research design, and it remains a challenge for positivist/post-positivist to use qualitative approaches that are rooted in more interpretivist frameworks.

Nevertheless, qualitative research offers numerous strengths essential to the early phases of research and differs in important ways from the assumptions and goals that underlie quantitative studies. First, qualitative research seeks to provide rich descriptions and understanding of phenomena as a means for transferability of knowledge (Hoepfl, 1997), as opposed to the primary goal of generalizability that guides quantitative studies. Rich and descriptive data presented in qualitative research enable transferable findings that can be applied to other research sites. Specifically, the transferability of qualitative research allows readers to extract findings from one study toward identifying elements that might be found in another community or research site of interest.

Second, qualitative research values creating knowledge *in situ*, highlighting the context as a critical feature of the methodology (Borrego et al., 2009; Van Note Chism et al., 2008). Even in quantitative work, context may not be highlighted as a forefront concern, but context asserts the assumptions to be made and impacts the analysis. For qualitative work, context requires a detailed understanding of the setting in which the phenomenon is occurring. Because of the need for detail, the in-depth oriented approaches of interviews and observations are common, as is textual analysis of open-ended questions in surveys or focus groups (Borrego et al., 2009; Golafshani, 2003; Leydens et al., 2004; Patton, 2002; Van Note Chism et al., 2008). For in-depth approaches, the data implementation and data analysis are time-consuming and rigorous, specifically due to the iterative processes that occur in order to develop an appropriate protocol for research questions, to ensure ethical and justifiable access to participants, and to acquire sound and complete findings from the data. In turn, qualitative research establishes credible and viable findings that provide tangible, transferable, and powerful insights.

Third, findings from ethnographic work most specifically and qualitative research generally, are often presented in the form of "thick descriptions" (Geertz, 1973) that feature the voices of the participants prominently to aid in the readers' deep understanding of the phenomenon being examined. Such thick descriptions and detail-oriented approaches allow for in-depth insights into people's lived experiences; this is particularly critical in exploring new environments and understudied populations whose voices may be washed out by quantitative surveys or may lack the support and understanding from the general population. Similar to how groupthink discourages a person from sharing their own voice, understudied populations may feel inhibited in sharing different or unvoiced perspectives. Hence, qualitative research can elicit important yet unanticipated insights that can lend way to additional, more structured studies.

2.3 Qualitative Research in Engineering Design

The notion of qualitative research is not new to engineering design; in fact, there have been several studies that have implemented qualitative methods; methods ranging from using interviews (Eng et al., 2017; Meluso & Austin-Breneman, 2018; Schaffhausen & Kowalewski, 2015) to ethnography or ethnographic informed methods (Bucciarelli, 1988; Lauff et al., 2018) as a means to collect data or using informed coding processes (Hey et al., 2007; Reap & Bras, 2014) to integrating a comparative qualitative research methodology (Fu et al., 2014) to analyze data. The use of these methods forwards aims to gather insights into various phenomena. For example, researchers have implemented qualitative methods in order to identify behaviors that are used in cross-disciplinary design (Adams et al., 2009). Additionally, qualitative approaches have created insight into the strategies that experts use in design (Cross & Cross, 1998), and how they address design tasks (Daly et al., 2012a). In a comparison of expert and novice designers, researchers used observation and interviews as a means to examine the patterns for how the experts and novices compare in their approaches to solving a design task (Ahmed et al., 2003). Expert design teams have also been observed via an ethnographic approach (the study of culture) which has resulted in an understanding how design teams engage in three different social processes: constraining, naming, or deciding in design (Bucciarelli, 1988). Moreover, the front-end design stages have been examined, and strategies have emerged to help designers generate solutions to design tasks (Daly et al., 2012a), and also researchers were able to craft a human-centered design framework by using qualitative methods to study the qualitatively different ways that students experience human-centered design (Zoltowski et al., 2012).

2.4 Studies in Engineering Design Relevant Towards Learning and Makerspaces

2.4.1 Student Design Learning

The learning characterized in engineering design highlights the need for hands-on, real-world experiences that foster critical thinking, problem-solving, and iterating through the design process. Studies have looked at learning in engineering design through multiple facets, whether through product dissection (Goeser et al., 2011; McKenna et al., 2008;

Starkey et al., 2018; Starkey et al., 2016), functional modeling (Nagel et al., 2013; Nagel et al., 2014, 2016; Nagel et al., 2015; Riggs et al., 2016; Tomko et al., 2017c), concept generation (Daly et al., 2016; Daly et al., 2012b; Gray et al., 2015; Shealy et al., 2018; Yilmaz et al., 2011), sketching (Hilton et al., 2018a), prototyping (Menold et al., 2018; Menold et al., 2017, 2019), expertise (Ahmed et al., 2003; Crismond, 2001; Cross & Cross, 1998; Deininger et al., 2017; Viswanathan & Linsey, 2011c), or design competitions (Lumkes Jr., 2006; Walden et al., 2015; Williams et al., 2015). Research in engineering design supports a collection of diverse and extensive topics, notably as they query the learning of engineering design students.

Because the design process involves a progression and iteration among various stages, engineer design can be explored in numerous avenues regarding student learning in the classroom or via controlled studies. One avenue examines student design learning via product dissection. In efforts to understand differences between physical dissection and virtual dissection, Toh et al. (2015) examined first-year students and showed that physical dissection improves student self-efficacy, but no apparent differences occur for student learning and retention, verifying the patterns seen in previous studies (Goeser et al., 2011; McKenna et al., 2008). In order to identify if other factors impacted learning through product dissection, a factorial experiment examining product's type of dissection, power source, and complexity identified that the student's use of virtual dissection environments is more efficient than physical dissection, but there remain comparable and similar learning outcomes for between virtual and physical dissection methods (Starkey et al., 2016). Looking at how dissection impacts concept generation, students engaging in a team physical product dissection are able to have less fixation during the brainstorming process

(Toh et al., 2014), but changes in the type of product dissection activity are not shown to influence the uniqueness and usefulness of concepts generated (Starkey et al., 2018). For concept generation in general, the type of method that a student uses causes differences in the activation of areas of the brain involved in spatial memory, abstract reasoning, and cognitive flexibility (Shealy et al., 2018). The difference in concept generation techniques are also shown in the number of concepts that students generate, where a hybrid 6-3-5/C-Sketch method helps to produce the greatest quantity of concepts compared to brainstorming, the gallery method, 6-3-5 along, and C-sketch alone (Linsey et al., 2005). However, students produce the most number of concepts through brainstorming in a 25-minute period, when compared to using design heuristics and morphological analysis, but the practicality of concepts is significantly higher when students use design heuristics (Daly et al., 2016). Although design tools can be used to help support the early phases of design, students tend to select concepts that receive high-ratings and match their preconceived expectations (Zheng et al., 2018), which shows that even in controlled efforts to gain insights into student learning of the classroom, there remain challenges towards inspiring and improving student learning.

Another avenue of student learning examines design modeling techniques, such as functional modeling (Nagel et al., 2012; Nagel et al., 2013; Nagel et al., 2014, 2016; Nagel et al., 2015; Riggs et al., 2016; Tomko et al., 2017c), sketching (Hilton et al., 2018a), and prototyping (Menold et al., 2018; Menold et al., 2017, 2019). While functional models offer a means for finding and fixing problems before going into the production phase (Houde & Hill, 1997), assessing functional modeling is not without its challenges. In order to create a standardized means for assessing functional models, Nagel et al. (2015) created an 18-question functional modeling rubric, which found that a student's ability to create an appropriate functional model for a bicycle depended on how they were taught functional modeling. While the method for which a modeling technique is taught impacts student learning, the *type* of modeling technique will also impact student learning. For example, computer-aided design offers students a means to make modifications to existing design and also to make drawings clear and aesthetically neat (Dally & Zhang, 1993); however, students improved in their spatial reasoning skills after undergoing instruction in free-hand sketching, but there remained no improvement after instruction in computer-aided design (Hilton et al., 2018a).

Further, when taking a concept into the prototyping phase, students' performance and choice of materials in a design tasks are impacted by their tinkering self-efficacy, engineering design-self efficacy, and familiarity with specific tools, which indicates the significance that hands-on projects have on implicit learning and self-efficacy (Menold et al., 2018). It alters students' decisions during the design phase when they have a structured prototyping framework to follow (Menold et al., 2017, 2019). Seemingly, the impact and benefits that prototyping has on student learning may carry into the prototyping seen in the makerspaces, where students engage in model building, tinkering, and engineering design.

2.4.2 The Benefits of Physical Modeling

Through physical modeling and representations, individuals are further able to engage in the design process as physical modeling helps them to imagine concepts more clearly, determine implicit elements of a design, confirm assumptions and functionality of ideas, select concepts, and increase communication among team members in the process

(Boujut & Blanco, 2003; Carlile, 2002; Hannah, 2009; Harrison & Minneman, 1997; Horton, 1997; Lidwell et al., 2003; McMohan, 1994; Michaelraj, 2009; Stowe, 2008). Because physical models help to showcase the functionality of ideas (Acuna & Sosa, 2010), there is less risk in the initial phases of the design process concerning a product's market acceptability and user features (Andreasen & Hein, 1987). Physical models capture and provide necessary information that was not previously available to designers, which can help them to further engage in the design process and also minimize costs (Dijk et al., 1998; Henderson, 1999). Information that can help both graduate design teams or Toyota designers be able to find or visualize flaws in a design, before putting time and money into manufacturing a flawed product (Kiriyama & Yamamoto, 1998; Ward et al., 1995).

Building physical models can help student design teams in identifying the problem and also in recognizing potential unwanted behaviors of their ideas (Horton, 1997; Horton & Radcliffe, 1995; Raucent & Johnson, 1997). Despite these benefits for student designers, professional designers are more likely than students to incorporate physical modeling as a means to understand and gain more insights into the design space (i.e., the abstract thinking space) (Smith & Leong, 1998). Using physical models in the design process has helped in identifying where energy losses would occur in a photovoltaic desalination plant (Bucciarelli, 1994), in increasing efficiency in the design and development of control systems (Faithfull et al., 2001), and in forwarding the design process compared to iterating without physical models (Dow & Klemmer, 2011). Additionally, the process of building and testing physical models helps to alleviate design fixation effects, especially towards undesirable features, which can thereby enable a design of better quality (Viswanathan & Linsey, 2011a, 2011b, 2012a, 2012b). In physical modeling, an individual's fixation to a concept depends on the cost of resources that they have already invested into a model (sunk cost); when the cost of resources is lower, then there is less fixation to a concept (Viswanathan & Linsey, 2010, 2012a, 2013), which indicates the importance of low-fidelity prototypes for engineering design. Such low-fidelity physical models are common in the makerspace; however, this type of learning through physical means has yet to be thoroughly studied in a makerspace.

2.5 Communities of Practice

While a place for building, makerspaces also act as a professional community of practice (COP). A community of practice is a group of people who share a common passion in a domain of interest and deepen their knowledge within this domain through recurring shared social interactions (Lave & Wenger, 1991). However, this is not to be confused with a community of interest (COI) that entails a group of people with a common interest who come together to discuss the topic of interest, where the people involved are not necessarily experts or practitioners of a domain. Communities of practice promote an individual's quest and understanding of identity through negotiating competence via social interactions within a domain of expertise (Farnsworth et al., 2016). Members in the community of practice engage in both guiding and receiving guidance from each other in collaborative social activities (Kriner et al., 2015). These communities focus on knowledgeability, which exceeds mere knowledge acquisition and moves towards one's experience and identity that comes from practicing in a domain.

The communities of practice (COP) concept emerged out of the work of researchers Jean Lave and Etienne Wenger. Their efforts sought to understand the learning that occurred in the historical forms of apprenticeship and the form of "apprenticeship" inferred in the cognitive and educational research. Examining learning as a situated activity led to unpacking the concept of situated learning, which characterized learning as "an integral and inseparable aspect of social practice" and further "as legitimate peripheral participation in communities of practice" (Lave & Wenger, 1991, p. 31). Through situated learning, individuals learn and negotiate meaning via contextualized social interactions of actual real-world environments (Lave & Wenger, 1991). This form of learning emphasizes that the whole person has a relationship to the world, that learning permeates every activity, and that meaning is renegotiated through present circumstances (Lave & Wenger, 1991).

Where learning is integral to social practice, an individual's engagement in social practice is referred to as legitimate peripheral participation. Legitimate peripheral participation is an individual's belonging and gaining membership into a community. Legitimacy refers to the appropriate belonging into a community which further posits the content of knowledge acquired. For example, a woman student without a making background gains legitimacy into an academic makerspace COP as they acquire more making knowledge (see Figure 3). This process engages peripherality, which "suggests that there are multiple, varied, more- or less-engaged and –inclusive ways of being located in the fields of participation defined by a community of practice. Peripheral participation is about being located in the social world. *Changing* locations and perspectives are part of an actor's learning trajectories, developing identities, and forms of membership." (Lave & Wenger, 1991, p. 36). This indicates that for a makerspace COP that there are multiple ways in which an individual engages and participates in the community activities. The process of legitimate peripheral participation then leads towards an individual’s full participation in a community of practice.

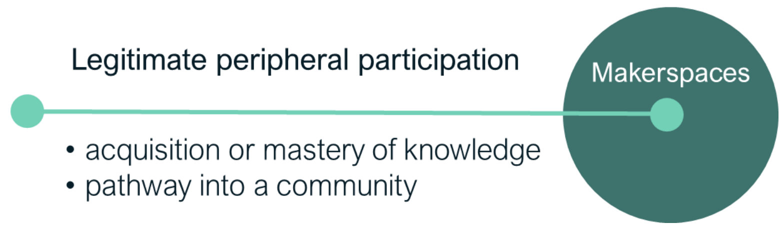

Figure 3: Legitimate peripheral participation affords legitimacy in a makerspace.

The constructs of a community of practice framework are highly valuable for understanding a variety of concepts, such as the work environment (Brown & Duguid, 1991), power dynamics (Contu & Willmott, 2003; Huzzard, 2004), and specifically learning, identity, and practice (Baker & Beames, 2016; Donath et al., 2005; Fincher & Tenenberg, 2006; Gilbuena et al., 2015; Handley et al., 2006). In the work environment, a company utilizes conventional job descriptions as means to improve the practices of the employees at work; however, this negates the organic ways in which people work and learn through a community of practice (Brown & Duguid, 1991). Beyond the scope of organizational learning, Contu and Willmott (2003) argue for how power dynamics factor into access and continued membership in a community of practice, where legitimate peripheral participation “highlights the power-invested process of bestowing a degree of legitimacy upon novices as a normal condition of participation in learning processes” (p.285). Moreover, COPs have helped in identifying transition pedagogies for students as the transition from high school to the university (Baker & Beames, 2016). COPs have been used to examine the learning of researchers in computer science education (Fincher &

Tenenberg, 2006)) and in the development of professional skills for both disciplinary and industry communities (Gilbuena et al., 2015).

2.6 Constructs of COP in Engineering

In particular, the constructs of a community of practice allow for insights into engineering practice, such as in the mastery or acquisition of knowledge and pathways into a field. First, the type of situated learning in a community of practice highlights mastery of knowledge through contextualized experiences (Patel, 2017). Given that the professional work setting is a community of practice (Brown & Duguid, 1991), Bornasal et al. (2018) examine how practicing engineers at a private consulting engineering firm acquire and use contextualized conceptual knowledge at their job. While the mastery of knowledge is linked to one's ability to be able to transfer knowledge from one setting (school) to another (work) (Litzinger et al., 2011; Streveler et al., 2008), there remains challenges in bridging the gap between student educational experiences and their ability solve contextualized ill-defined problems (Atman et al., 2010; Katz, 1993; Martin et al., 2005; Passow, 2012; Russell & Stouffer, 2005; Sheppard et al., 2009; Trevelyan, 2010). In a similar vein, after four years of engineering or participating in an engineering design course, students were found to develop engineering design language common to both their specified programs/institution and to the larger engineering COP (Atman et al., 2008b). While work seeks to understand how to bring students into the professional engineering setting (Cruz & Kellam, 2018), it is speculated that makerspaces could provide the bridge between industry and academia (Pernia-Espinoza et al., 2017). Although little work has examined pathways into engineering makerspaces, researchers have sought to understand student pathways into engineering.

Second, through legitimate peripheral participation, an individual pursues a pathway into a community. Engineering education research has sought to understand students' pathways into engineering. Of particular interest has been student's persistence in engineering. For example, it has been shown that the persistence of engineering undergraduate students is challenged by them not being sufficiently prepared for and feeling overwhelmed by the engineering workload, having feelings of self-doubt or disappointment, being poorly advised, or having misconceptions or limited knowledge of what engineering entails (Adelman, 1998; Cruz & Kellam, 2018; Haag et al., 2007; Hutchison-Green et al., 2008; Koenig et al., 2012; Meyer & Marx, 2014; Ohland et al., 2008; Seymour & Hewitt, 1997; Tseng et al., 2011). Overall, students come into engineering with little understanding of what the program requires of them, but the students are able to come to understand how to persist in their coursework and their own engineering journey through interacting with advisors, teachers, and peers (Cruz & Kellam, 2018). While student persistence in their pathways are further enhanced by positive faculty interactions (Chen et al., 2008), faculty are encouraged to integrate more authentic learning experiences since students are now more accustomed to learning outside of the classroom (Chubin et al., 2008). In fact, students who engaged in undergraduate engineering design research were able to understand engineering design concepts more fully and identify poor engineering design concepts (Scott et al., 2001). Ultimately, looking at pathways through lens of persistence helped to show that what matters in the education setting does not necessarily matter for the professional setting (Stevens et al., 2008), and also helped to change the research perspective from one of pipeline metaphors to the pathway metaphor (Atman et al., 2008a; Watson & Froyd, 2007).

Recently, Lord et al. (2019) published work on persistence in engineering education that expanded the pipeline and pathway metaphor into an ecosystem. While pipelines showed the typical approach as students "leak" out of the system, pathways focus on the multiple entry points into a system. Meanwhile, the ecosystem approach allows for the more complex aspects of a system to be recognized. However, Lord et al.'s (2019) work focus on a quantitative perspective of gauging retention and attraction towards a discipline. In their discussion, the authors argue that the ecosystem approach offers insights into contextual factors such as multiple influential actors, gatekeepers, power relations, tacit knowledge, knowledge transmission, and disciplinary cultures (see Figure 4). In order to access insights into these factors, we argue for the use of qualitative research methods that allow for rich insights into contextualized experiences. Especially given that "within this ecosystem, the more common normative pathways exist alongside more complex behaviors" (p. 49), we can understand the complex pathways into the makerspace through examining a making ecosystem.

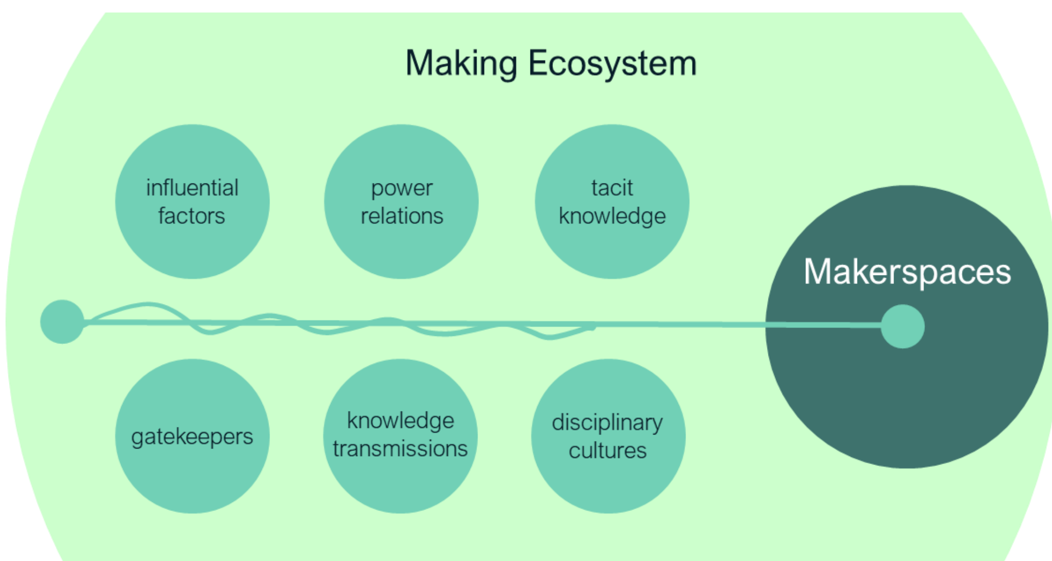

Figure 4: Factors of consideration in a making ecosystem.

Evidently, these pipeline and pathways metaphors have been studied extensively regarding persistence in engineering education. In turn, we can take the insights from these studies and implement them into our research endeavor for studying women in makerspaces. First, though, we immerse ourselves into the literature regarding women in engineering in order to understand the underlying themes that resonate in the narratives and pathways for women engineers.

2.7 Women in Engineering

Women continue to be underrepresented in the engineering field (Labor, 2017), which is heavily embedded in a masculine culture (Hatmaker, 2013; Herman et al., 2013; Hewlett et al., 2008; Miller, 2004; Sharp et al., 2012). Not only that, but the engineering profession has been gender-typed as masculine (Cockburn, 1985; Hatmaker, 2013) and due to gender stereotypes, the engineering profession considers men to be most appropriate for the work (Ely & Padavic, 2007; Williams, 1995). These cultural nuances are evidenced in the fact that the engineering profession can be seen as the most male-dominated profession in the USA (Fox, 2006). This type of masculine culture has greatly impacted women in the profession. In turn, women have taken on demeanors that follow suit to the masculine nature of the profession, where they are more masculine in their interactions with others (Faulkner, 2000; Jorgenson, 2002; Kvande, 1999; McIlwee & Robinson, 1992) or ignore potential gender differences by describing the workplace as neutral while considering themselves to be just like the men, almost a conceptual man of sorts (Jorgenson, 2002; Kvande, 1999; Ranson, 2005). Changing the nature of interaction then forwards the woman's legitimacy and membership into the brotherhood of engineering (Hughes, 1958).

Women adopt these strategies and mindsets because the engineering profession excludes women from the conversation (Faulkner, 2009a; Miller, 2004). They face resistance from co-workers as they are seen as anomalies to the profession (Faulkner, 2009b; Miller, 2004). Women struggle to be seen as belonging and gain an engineering identity in a profession that is seemingly incompatible for women (Eisenhart & Finkel, 1998; Faulkner, 2000, 2009a, 2009b; Jorgenson, 2002; Kvande, 1999; Tonso, 2007). More importantly, women's competence is already negated by the fact that "competence as an engineer is a function of how well one presents an image of an aggressive, competitive, technically oriented person…. To be taken as an engineer is to look like an engineer, talk like an engineer, and act like an engineer. Of particular importance in this presentation of self is the image of hands-on competence" (McIlwee & Robinson, 1992, pp. 20-21). Despite being equally competent in the technical aspects of engineering, gendered expectations cause barriers (Sharp et al., 2012) and inherent neglect for teaching young women hands-on competence. Women face daily barriers (Miller, 2004; Powell et al., 2009; Rhoton, 2011) and engage in both coping strategies (Jorgenson, 2002; Khilji & Pumroy, 2018; Miller, 2004; Watts, 2009) and impression management (Goffman, 1959) as a means to experience validating interactions that help for a sense of belonging (Hatmaker, 2013).

Unfortunately, while makerspaces are seen as these open, collaborative learning environments, the need for hands-on competence as a form of legitimacy can quickly place women at a disadvantage. However, "there's some unspoken societal rules that have to do with makerspaces, and it ends up being why there are more men in engineering, or why there are more men showing up to a makerspace. These unspoken rules assign gender to the use of tools or the ability to make and design things" (Terry Nordock in *The Riveter* (2018)). While these unspoken rules assign gender to tools and designing, there is also the fact that the women engage in more art-centric making that is not acknowledged as 'making' (Faulkner & McClard, 2014). Further, with the gender association to a makerspace, women are likely to avoid makerspaces due to them being generally dominated by men (Faulkner & McClard, 2014). In efforts to understand the woman making experience, Intel and HarrisPoll (2014) conducted a mixed-methods study of girls and women makers worldwide. In this study, Intel found that women makers are more likely than male makers to come to making through multiple pathways, including engineering, computer science, arts, and design. (Intel & HarrisPoll, 2014). Further, through encouragement and support in their projects, women will participate in makerspace in order to be able to present their work and collaborate with others (Bean et al., 2015). While these studies have focused on a variety of different setting, there remains little understanding of how women student pathways into an academic engineering-oriented makerspace are impacted at the university setting and what they are learning from their involvement in makerspaces.

2.8 Summary of Literature and Conclusions

Makerspaces are a complex dynamic phenomenon that engages a wide variety of phenomenon that set the groundwork for expanding the understanding of these spaces. While there are numerous claims centered around makerspaces, there remains little empirical evidence that forwards the conversation on the learning the occurs in these spaces at the higher education level, particularly for women students. As the makerspace become integrated onto college campuses, efforts prompted an understanding of best practices but focused primarily on the outcomes versus trying to understanding the diverse set of narratives associated with building a makerspace. Other efforts for studying the makerspace have focused on student self-efficacy and classifications of makerspaces, but the efforts to understand learning have yet to thoroughly examine the breadth of learning at higher education.

However, efforts to study this learning in makerspaces requires taking on qualitative research methods that allow for the study into complex phenomenon and generate rich datasets. While qualitative research has been implemented in engineering design studies, the use of phenomenologically based interviewing methods has yet to be explored. Further, engineering design has posited efforts to understand student learning and physical modeling with outcomes that could potentially be similar to that of student learning in makerspaces. Still, because a makerspace is more of a professional community of practice, the methods and constructs associated with the studies of students in engineering design are less appropriate, where legitimate peripheral participation impacts the acquisition of knowledge, learning, and an individual's pathway into the community of practice.

Particularly for engineering, the pathways of students have been examined through investigating their persistence. This investigation has led to efforts for understanding student persistence in an ecosystem. These efforts demonstrated the value of the ecosystem approach for addressing contextualized factors that impact a student's pathway. However, these types of contextualized factors are not easily understood using quantitative methodologies; rather a qualitative approach can generate deep insights for understanding contextualized factors that impact a student's pathway. For instance, being a woman in engineering has numerous considerations that would highly impact her pathway into a makerspace and through a making ecosystem.

In summary, postulating that the act of making stimulates learning, a widespread effort prompted the integration of makerspaces on college campuses. From community colleges to research-based higher education institutions, large investments were and still are being made to advance the making spirit and encourage non-traditional learning in academic settings. However, efforts to understand what makes a makerspace require investigating the beginning narratives of various university makerspace. Further, while optimistic that students are taking advantage of the makerspace resources and are learning from their experiences, there needs to be a more direct effort to understand the learning, if any, that is occurring in the makerspace. The makerspace is labeled as an open, learning environment where students can design, create, innovate, and collaborate (Pernia-Espinoza et al., 2017; Radniecki et al., 2016). In response, we investigate the claims of this statement by examining how university makerspaces support women student learning.

CHAPTER 3. A METHODOLOGICAL ROADMAP

Using phenomenological interviews to qualitatively evaluate how academic makerspaces support women student learning.

This chapter forwards a qualitative methodology novel to engineering design research – phenomenologically based interviewing. This chapter presents the qualitative methodology in the form of a roadmap for engineering design researchers. To demonstrate the methodology in practice, the methodology is then described in the context of studying how academic makerspaces support women student learning, since this has the potential to capture the nuances of learning in a making environment through a reflexive interview format that aims to understand lived experiences of women students. Then, this chapter further forwards and discusses how the presented methodology is applicable to other research endeavors in engineering design.

3.1 Phenomenologically Based Interviewing as a Form of Qualitative Inquiry

Interviewing is an effective means to gain rich insights into the lived experiences encapsulated in a person's narrative or story. In essence, interviews elicit stories; a story is a way of knowing, and the act of telling a story prompts meaning-making (Seidman, 2006). Through interviews, the voices of the participants are heard in context. Similar to how in engineering design research the context determines the methodology and the findings, the participants' experiences placed in the context of their personal narratives then help to inform the meaning and reasons behind their engagement in a particular phenomenon.

More specifically, the process of phenomenologically based interviewing, presented in this dissertation, utilizes open-ended questions aimed to provoke the participants to reconstruct experiences pertaining to a specific topic of interest. The approach is based on the phenomenology of Alfred Schutz (1967), who argues that phenomenology, or the study of experience, offers an objective study for phenomena in social science. The in-depth phenomenologically based interviewing approach, outlined in Seidman (2006), has been used in a variety of education-oriented studies including first year teaching experiences for English teachers (Cook, 2009), the experiences of ESL students and ESL teachers (Gabriel, 1997; Young, 1990), and the experiences of student teachers (Compagnone, 1995; O'Donnell, 1989). This form of interviewing is also particularly useful for generating rich, in-depth, and thorough accounts of the lived experiences of understudied and marginalized populations (Seidman, 2006). The in-depth phenomenologically based interviewing approach illuminates the varied experiences of understudied or underrepresented groups such as African-American performing artist-teachers and Black jazz musician teachers at colleges or universities (Hardin, 1987; Jenoure, 1995), along with gender issues in student teaching (Miller, 1997). The phenomenologically based interviewing proves highly useful for exploring studies that involve education, understudied or underrepresented populations, and complex phenomenon.

3.2 The Phenomenological Methodology

The in-depth phenomenologically based interviewing approach is a specific process of reflexive open-ended interviews outlined in Irving Seidman's *Interviewing as a Qualitative Research* (see Seidman (2006) for more details). The method couples the theoretical frameworks of life history interviewing (Bertaux, 1981) and in-depth interviewing based in phenomenology by Alfred Schutz (1967). In this process, three consecutive 90-minute interviews are conducted and designed to evoke a person's lived experiences or narrative through an open-ended, semi-structured protocol. Each interview delves into different aspects of a person's lived experience (Figure 5) as it pertains to a specific topic. In short, a phenomenological interview seeks to answer the question: "What is the meaning of X?" Seidman argues that these three interviews should be conducted in relatively close proximity to one another, over a course of two-to-three weeks, to provide both the opportunity for a sense of continuity and ample time for reflection between interviews. In the following, we describe how the processes of phenomenological interviewing can be innovated and modified to study features of engineering design. This interview process could be readily applied to various questions of interest related to diverse populations.

Figure 5: The in-depth phenomenologically based interview process.

3.2.1 First Interview

The first interview concentrates on a person's life history. The participants are asked to reconstruct their experiences that have led to their current role or situation. In order to gain insight into their lived experiences from a life history standpoint, the interview is centered on *how* the participant became engaged in their current role as opposed to *why* they became engaged. An interview focusing on *how* allows for the participant to openly describe their experiences, whereas an interview that focuses on *why* confines the scope of the interview, points to a particular objective and can prevent the participant from recollecting and reflecting on their experiences. By focusing on *how* a person becomes involved in the phenomenon of interest, this starts and establishes the interview series to be in the context of the participant's life. Through this, the participant shares the experiences that led them into the current role or situation; because engineering design occurs *through* experience, it is important to capture the life history and context of the lived experiences of engineering design.

3.2.2 Second Interview

In the second interview, the person is invited to describe the details of their current lived experience. In order to elicit a thorough account of the present lived experiences, participants may be asked to bring an artifact to the interview with them. While this is not a part of the standard protocol for the in-depth interviewing process described by Seidman, the artifact provides a starting discussion point for the interview and also provides a tangible reference for greater contextual support to the participants' descriptions. This modification is particularly useful for engineering design, given the focus on the design process and the making of physical or tangible artifacts (e.g., prototyping). Given the tangible reference, the participants are able to reconstruct their experiences around the artifact, which becomes the gateway into the participant expanding on their current lived experiences. These artifacts are able to inform the interviewer of follow-up questions, which invite the participants to provide thorough accounts of the meanings they have around the phenomenon of interest, thereby setting the foundation for the third interview.

3.2.3 Third Interview

The third interview directs the participant to reflect on the *meaning* of their lived experiences. Because talking about an experience elicits meanings (Vygotsky, 1987), meaning-making inherently occurs within first and second interviews when the participant describes their past and current experiences. In turn, the developed narrative from the first and second interviews creates a foundation for the participant to reflect on their lived experiences. In order to focus the third interview contextually, the interviewer may open the interview by asking the participant to draw a timeline on paper of their experiences around the phenomenon of interest. Again, the prompt for a timeline is not in the protocol that is articulated by Seidman for the in-depth interviewing approach. However, for the purposes of engineering design, a physical timeline creates a starting point to springboard the conversation while also helping the participants to reiterate and reaffirm their lived experiences, to potentially fill in gaps that may not be noticeable in a verbal narrative from the first and second interviews, and to then have a tangible timeline that they could reflect upon throughout the interview. Hence, the act of creating a visual timeline allows the participants to reflect on their life history and current lived experiences in a concrete way—similar to how television shows will have a “previously on” segment at the beginning of each show. This provides context and a quick refresher for the participants who are then able to extract meaning from their experiences using the visual timeline in front of them.

3.2.4 Interviews and Engineering Design

The in-depth phenomenologically based interviewing approach has great potential to contribute toward understanding the learning that evolves from engineering design experiences, as it invites participants to offer a deep reflection of their lived experiences in engineering design; whereas, inviting students to respond to the prompt, "what are you learning?" is likely to result in a conventional, academically conditioned, or incomplete response. In contrast, this methodology places such a question after the person has reconstructed their experience and informed the interviewer about the narrative. In such a way, the interviewer can point to different moments in the participant's reconstructed narrative and question the relevance to the participant's learning through the various engineering design experiences. Context is necessary for this kind of meaningful reflection on learning. Otherwise, there is little chance of actually investigating the meaning of an experience (Patton, 1989) and understanding how a student is potentially learning through their engineering design experiences. From reconstructing their lived experiences through life history, current experiences, and meaning, the participants provide stories and describe experiences that are abundant in implicit and explicit engineering design learning characteristics.

3.2.5 The Single, Targeted Interview

The in-depth phenomenologically based interviewing process is time-consuming, and for engineering design researchers new to qualitative methods, the time and energy needed for implementing this type of methodology may be challenging to negotiate. Interviewing one participant estimates to occupying roughly 4.5 hours, and obtaining a sample size of 20 is at least 90 hours of interviews, which does not even include prep time and potentially running over time. More importantly, effective interviewing takes practice and experience, which can quickly drain the energy of a researcher new to qualitative methods. In order to reach a larger sample size and adjust the approach for engineering design purposes, the in-depth phenomenologically based interviewing protocol can be modified into a single, focused 60 to 90-minute interview protocol. First, this single interview protocol is rooted in the findings and themes that emerge from conducting the in-depth phenomenologically based interviews with a small sample size (e.g., five participants). Then, the interviewing protocol adapts the original protocol so as to draw a concise, yet thorough narrative from the participants. In turn, this led to an interview protocol that begins by asking participants to draw a timeline on paper of their experiences around a phenomenon of interest, to clarify their engagement in the phenomenon, and to share experiences involving artifacts through pictures on their phone. Utilizing the single, targeted interview increases the opportunity to talk to more participants while still engaging a detailed narrative of the participants' lived experiences.

3.3 The Interviewer

When using interviewing as a research method, it becomes important for the presented research to discuss and describe the interviewer. The interviewer is the instrument of data collection, and thereby, researchers must consider the inherent characteristics or biases that the interviewer may carry into the interviewing process (Figure 6). Throughout the interviewing process, the interviewer and the participant are co-creators of the story being built, where the interviewer prompts and probes as the participant fills in the narrative. In turn, a social relationship begins to form between the interviewer and the participant, and this relationship is maintained during the interview process and ended respectfully upon completion of the interview(s) (Dexter, 1970; Mischler, 1986). Every interviewer-participant relationship is personalized and unique, reflecting how the interviewer and participant interact with each other. In particular, with the three-series interview process, the relationship between the interviewer and the participant is different than a relationship developed during a one-time interview. Because the interviewer-participant relationship characterizes and frames the interview, it becomes necessary to describe both the interviewer and the participants in the study along with the process for recruiting participants. This process is crucial, as it demonstrates that the interviewer takes the time to inform the participant of the research, allows the participants to ask questions before consenting, and establishes trust with the participants. Also, in the data collection and data analysis process, it is highly suggested that the interviewer take on the role of the main researcher who establishes the interview protocol, interviews the participants, and analyzes the data. In this way, the interviewer is fully immersed in the data and understands the underlying nuances within the data. Further on this point, if the research team cannot maintain one researcher as the interviewer for the full research design (as is the case for multi-university studies), the research team should ensure that only one researcher collect each set of the 90-minute interviews, and also keep the number of interviewers to a minimum. The interviewers should have similar training and communication with one another, as a means to ensure little variability in the interviews.

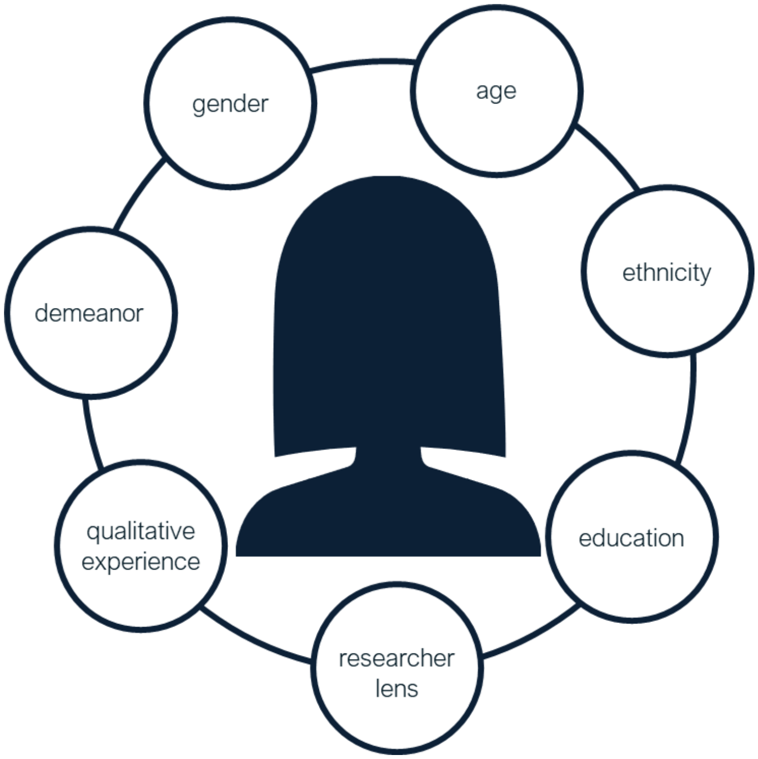

Figure 6: Characteristics that an interviewer carries into the interviewing process.

3.4 The Interviewer's Lens

There are different ways to view knowledge and reality. While this is not addressed in quantitative research, the researcher or interviewer's lens is imperative to the methodology and data analysis processes used in qualitative research. Generally speaking, quantitative research takes on a positivist/post-positivist lens. In this lens, the research assumes a true reality that exists and is to be discovered. Another common lens is the interpretive lens. The interpretive lens emphasizes that knowledge and reality are constructed, communicated, and mediated. If asked whether a tree that falls in the forest makes a sound, the positivist/post-positivist would say "yes," and the interpretive point of view would say "it depends on the meaning of the word sound." As such, the lens used by the researcher(s) greatly impacts the methods, analysis, and findings. With phenomenological based interviewing, the interpretive lens allows for the researcher to extract the meanings of experiences as identified by the participants.

3.5 The Participants

Phenomenologically based interviewing requires the selection of participants who are most poised to offer insight into the meaning of the phenomenon under investigation. Participants are selected through purposive maximum variation to identify a heterogeneous group of participants who meet the criteria for the inquiry of interest. Often snowball sampling will also be necessary to recruit populations that difficult to reach, such as underrepresented student populations in engineering design. Snowball sampling is when initial informants refer the researcher to other individuals who would meet the criteria of eligibility for a study (Morgan, 2008). In purposeful sampling, cases are selected based on their potential to provide rich information regarding a certain topic, as per the available resources (Palinkas et al., 2015; Patton, 2002). Paired with purposive sampling, maximum variation sampling pertains to selecting sites and/or people (Tagg, 1985) that are truly representative of the larger population and that will provide relatability to a wide audience (Seidman, 2006). Maximum variation sampling also seeks to capture a wide range of variation or difference across a single population.

3.5.1 Sample size

For qualitative inquiry, the size of the sample is of lesser importance than the richness of the data itself, as prediction and generalizability are not the goals of qualitative inquiry. Rather, in these studies, the goal is to excavate the range of possible interpretations/experiences given a certain phenomenon until there are enough cases to reach theoretical saturation. Theoretical saturation is reached when analysis of data no longer yields new meanings (Douglas, 1976; Glaser & Strauss, 1967; Tracy, 2013), and the process for reaching theoretical saturation is described later (see Credibility section). The potential for saturation is dependent on the population size and the context of the research methods.

3.6 The Data Analysis

Qualitative research produces rich textual datasets that require the researchers to immerse themselves in the data as part of the analytical process. The phenomenologically based interviews produce a thorough and rich corpus of data for the development of grounded theories of learning. Grounded Theory Development (Charmaz, 2014; Glaser & Strauss, 1967; Strauss & Corbin, 1990) is an iterative process of qualitative data analysis that that seeks to build theory inductively. "In this methodology, theory may be generated initially from the data …then these may be elaborated and modified as incoming data are meticulously played against them" (Strauss & Corbin, 1994, p. 273). To clarify, when a researcher aspires to develop grounded theory, they examine the data systematically for emerging themes, with the goal that these themes will explain the workings of some aspect of the social world (grounded theory). The following describes the processes of analyzing the data – using constant comparison methods, data immersion, and coding – toward the construction of typologies for engineering design (Figure 7).

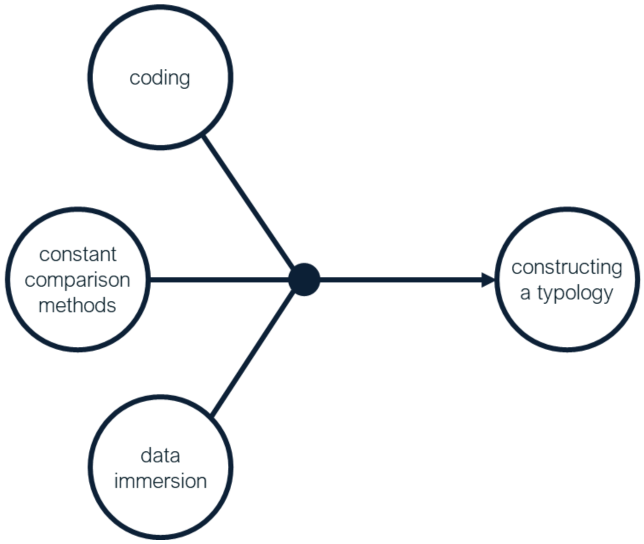

Figure 7: Data analysis process toward the construction of a typology.

3.6.1 Constant Comparative Method

At the heart of grounded theory is the constant comparative method, an iterative method that characterizes each phase of data analysis and interpretation. Through constant comparison, the data is continually being processed, examined, analyzed, and compared so as to inform the next steps for data collection and/or analysis. Specifically, the researcher moves line-by-line through the data, labeling each unit of data, and comparing to the next. From this iterative process of labeling and comparing units of data, broader interpretations of what is happening in the data are made by the researcher(s). During this process, the researcher is not addressing nor trying to match the data with a predetermined hypothesis or *a priori* sets of categories (Glaser & Strauss, 1967). As a result, researchers must engage in the analysis process with a willingness to be receptive to what emerges from the data. However, Strauss and Corbin (1990) argue for the importance of theoretical sensitivity of the researcher toward effective coding of data. That is, the researcher should be familiar with the literature and scholarly conversation regarding the area of inquiry such that the coding of the data is informed by that literature, yet still open to the perspectives and sometimes contrary experiences offered by the participants.

3.6.2 Data Immersion

Qualitative analysis begins as soon as the first set of interviews are completed and transcribed, starting with the primary researcher reviewing the full set of transcripts several times to familiarize themselves with the data and gain a holistic perspective. The purpose of the data immersion phase is for the researcher(s) to become familiar with the data and understand the nuances in the data. Through this initial data immersion phase, the researcher makes initial analytic memos noting points of interest. These initial memos may be important later in interpreting the data.

3.6.3 Coding

In order to arrive at grounded theory, data are analyzed through multiple cycles of coding (Glaser & Strauss, 1967). A code is "most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (Saldaña, 2016, p. 4). 'Coding' is the process of eliciting codes from the data; where for the in-depth interviewing process, the data are the language-based interview transcriptions. The process of coding in grounded theory development follows multiple phases of coding. While researchers are encouraged to explore various types of coding (see Saldaña (2016)), we highlight two types of coding that are commonly used together as two cycles of the coding process: open coding and axial coding. Open coding extracts and investigates attributes within the data, whereas axial coding methods refine the codes produced in the first cycle. Specifically, open coding is an exploratory process that decomposes the data into distinct parts while examining these parts for similarities and differences (Saldaña, 2016, p. 4). It is crucial that this process allows one to open their interpretations of the data to any potential theoretical directions (Charmaz, 2014). The second cycle implemented is called axial coding. Axial coding expands on the open coding, collects the codes, and reorganizes the codes to eliminate, converge, and compare so as to build categories. This process of identifying codes and eventually, themes in both phases is completed through the iterative process of constant comparison and "lumping" and "fracturing" data (Tracy, 2013). As a result, this process for analyzing the data and developing a coding scheme effectively produces a typology.

3.6.4 Constructing a Typology

While a code captures the essence of a segment of data, a typology embodies the ecosystem of the data, illuminating the broad categories or groupings of codes. That is, a typology is an arrangement of categories or 'types' as they pertain to a certain phenomenon of interest. In the case of the proposed methodology, the interview data may yield a variety of types: types of learning, types of experiences in engineering design, types of obstacles to learning in engineering design, among others, depending on the research question. According to Kluge (2000), "types are constructed in order to comprehend, understand, and explain complex social realities" (p. 1).

Typologies are constructed through iterative, analytical, and interpretive processes of moving back and forth between the open codes and the axial codes. In this case, the axial level codes are the categories or types. In creating a typology, the researcher discerns what kind of categories are of interest based upon the research question. For example, if the researcher is interested in the types of learning experiences participants have in an engineering design course, the researcher will group the open codes into "types of learning experiences." The open codes, then, ultimately characterize the attributes of each of the categories. For example, the type "learning by doing" may be composed of attributes in the data such "active," "hands-on," and "making."

An initial typology may begin to emerge after the analysis of two-to-three sets of interviews. Thereafter, the researcher codes the remaining interviews using the typology itself, seeking to refine categories and the attributes therein with each new interview analyzed. The data collection is considered complete once analysis reveals there to be no continued refinement of the typology.

3.7 Criteria for Trustworthiness

Qualitative researchers have argued that the criteria used to determine the trustworthiness of quantitative studies are inadequate for assessing the quality of qualitative research. Among watershed discussions regarding the construction of criteria for trustworthiness is Lincoln and Guba's (1985) assertion that naturalistic forms of inquiry should be assessed through the manner in which credibility (replacing "validity"), transferability (replacing "external validity"), dependability (replacing "reliability"), and confirmability (replacing "objectivity" or "neutrality") are evidenced. Later, recognizing that interpretative perspectives value the multiplicity of experiences of participants, they added the criterion of authenticity (Guba & Lincoln, 1989).

Later, building upon the debates among qualitative scholars, Tracy (2010) offered a comprehensive framework for evaluating the quality of qualitative research. Her framework takes into consideration Lincoln and Guba's (1985) foundational quality criteria while advancing a vocabulary that qualitative researchers can adopt, regardless of ontological perspective. Tracy's framework enables qualitative researchers to systematically evidence the trustworthiness of their work and equips reviewers to readily assess that work using a shared vocabulary, similar to how the vocabularies of validity and reliability enable a common set of standards for quantitative researchers. Specifically, Tracy (2010) argues that the quality of qualitative work can be assessed through the extent to which a work evidences eight criteria: worthy topic, rich rigor, sincerity, credibility, resonance, significant contribution, ethical, and meaningful coherence (see Figure 8).

- *Worthy topic*: The research is thought-provoking, engaging, important, timely, or relevant.
- *Rich rigor*: The research is conducted in an appropriate manner, where there is sufficient data and time, appropriate data collection and analysis processes, aligned theoretical constructs, and agreeable context.
- *Sincerity*: The research utilizes self-reflexivity and transparency.
- *Credibility*: The research is characterized by thick descriptions, triangulation, and member reflections.
- *Resonance*: The research influences the audience in a meaningful way, whether through transferability, natural generalization, or aesthetic merit.

- *Significant contribution*: The research transforms or revolutionizes a field of knowledge, perhaps in theory or methodology.

- *Ethical*: The research addresses situational, relational, or procedural conduct and integrity of the work.

- *Meaningful coherence*: The research achieves its' goals through implementing agreeable methods and attending to connections in the literature.

While all eight of these criteria are critical to demonstrating the quality of a qualitative research, the methodology presented in this dissertation concerns the demonstration of rich rigor, sincerity, meaningful coherence, credibility. In the following, we describe how to ensure each of these standards are evidenced when following this method.

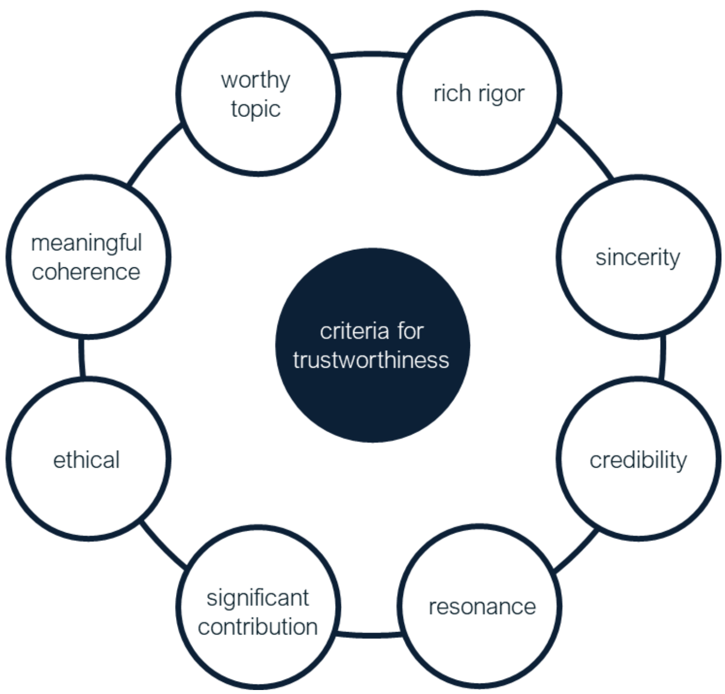

Figure 8: The eight criteria for trustworthiness in qualitative research.

3.7.1 Rich Rigor

Evidencing the rich rigor of a qualitative study requires demonstrating that the data and the type of data (artifacts, interviews, observations) are adequate for the knowledge claims advanced in the research. In doing so, researchers must look to both the quality and quantity of their data, their sampling methods, the appropriateness of the context studied, and the methods of data analysis. For the approach described in this dissertation, the dedication of three 90-minute interviews with each participant juxtaposed with targeted interviews that pull a larger sample size is an important marker of the depth of the data. Further, when conducting phenomenological interviews, assessing the quality and accuracy of the transcription is important to demonstrate the rigor of the methods (Creswell, 2007). Finally, purposive sampling methods are critical to demonstrating rigor. Through identifying participants who meet the criteria for the research investigation, researchers must determine the extent to which each potential participant has the experience to illuminate the *hows*, *whats,* and *meanings* of the phenomenon of interest in engineering design.

3.7.2 Sincerity

Sincerity is characterized by the demonstration of the authenticity of the research and its processes. Tracy (2010) argues that practices of self-reflexivity, which reveals the researcher's self-awareness, help ensure the researcher demonstrates an understanding of their own role and impact on the research. "Self-reflexive researchers examine their impact on the scene and note others' reactions to them" (p. 842), as demonstrated by the researchers making notes during interviews that reflect on the researcher's presence in the scene and their impact on participant's responses. In the phenomenologically based interviews, the interview transcripts showcase the researcher as having a role in data production, which thereby appears as part of the data itself. In addition to self-reflexivity, the researcher can evidence sincerity by offering transparency of the data collection and analysis process, including difficulties and obstacles during the research process. Such an audit trail of the data collection and analytical processes is an important part of accounting for the authenticity of the researcher. This is similar to what Lincoln and Guba (1985) referred to as the confirmability of the research process.

3.7.3 Meaningful Coherence

Through meaningful coherence, the researchers articulate how the research design accomplishes the specified goal(s), uses methods and practices that are compatible with the adopted theories and paradigms, and connects with the literature (Tracy, 2013). The assertion that the researcher(s) make should show how the numerous arguments and decisions logically connect to create a coherent story. For instance, phenomenologically based interviews are best suited for an interpretive lens, since the interviews are designed to explore the interpretations of each participant's experience of a certain phenomenon. However, engineering design research is quite positivist/post-positivist in nature; this creates challenges for other qualitative approaches that could be highly valuable and more appropriate than existing methods for gaining insights in engineering design. In order to be meaningfully coherent, engineering design researchers must carefully articulate how the approaches used in the research design are compatible. To illustrate, phenomenology and grounded theory are two distinct qualitative research approaches. In the methodology presented in this dissertation, neither approach is presented or used in its' 'pure' form. That is, the interviews are phenomenologically based, and the data analysis process utilizes grounded theory techniques. The researchers are not seeking to develop grounded theory, but more so to utilize the analysis techniques as a means to ensure rigor in the analysis process, especially for an engineering design audience. Further, interviewing was selected as a means to collect data, and the phenomenologically based interviews satisfied the need to explore lived experiences in engineering design. When interviewing is used as a means to collect data, the interviewing technique may also be seen as lacking a straightforward connection to the 'pure' methodological framework (Wimpenny & Gass, 2000), showcasing the compatibility of the various approaches used in the presented methodology.

3.7.4 Credibility

"Credibility refers to the trustworthiness, verisimilitude, and plausibility of the research findings" (Tracy, 2010, p. 842). Credibility can be evidenced in a variety of ways when using the presented research process. First, the researcher should provide detailed, thick, and rich descriptions of the data; these descriptions expose the meaning that the participants communicate in the interviews, which as often as possible should be in participant's own voices. Showing participants perspectives is crucial to unearthing the meanings of their experiences in engineering design and illuminating the construction of their learning processes. Further, presenting a detailed depiction of the participant's experiences and meanings allows the readers to draw their own conclusions and assess the strength of the researchers' interpretations and claims.

Second, interpretations can be triangulated by the cooperation of multiple researchers in the analysis and interpretation of the interview data. While only one researcher should collect each set of the 90-minute interviews in order to establish the rapport necessary to elicit the deep reflections on the meanings associated with engineering design, utilizing multiple researchers in the coding of the data can be valuable toward ensuring the clarity of the categories of meanings and demonstrating the agreement among multiple. We recommend that this be done in multiple stages. First, the interviewer reads through each complete set of interviews as they are transcribed in order to have a holistic framework for analyzing the data, and then the interviewer begins the first cycles of open coding. Second, as broader themes or categories begin to emerge during the initial coding stage, the interviewer should meet with co-researchers to consult with them on the emerging themes. The co-researchers should also read the full set of transcripts. Then, the team of researchers discusses the initial categories of the emerging typology, asking critical clarifying questions of each category in order to refine, distinguish, and then test examples from the data against the categories. Third, the interviewer returns to the next set of transcripts and repeats this process of coding and collaborative discussion with co-researchers until no new categories emerge in the data, reaching theoretical saturation.

"One practice often associated with triangulation is that of *inter-coder reliability*. Inter-coder reliability is only desirable when the researchers are claiming to code the data similarly" (Tracy, 2013, p. 236). This is pragmatic for researchers working within a positivist/post-positivist paradigm or who have a positivist/post-positivist audience, as is the case for engineering design. In qualitative research, there are two metrics to consider: inter-coder reliability and inter-coder agreement. Inter-coder reliability refers to the ability of two or more coders to select the same code for the same sample of text, given that the coders are in isolation of one another and are considered to be equally capable (Campbell et al., 2013). Inter-coder agreement is the ability of the same two or more coders to reconcile the discrepancies in their codes through discussion (Campbell et al., 2013).

The inter-coder metrics satisfy the positivist/post-positivist's propensity for numerical validation of the data analysis process. However, the inter-coder metrics must be used with caution, depending on the research lens. In the interpretive lens, the inter-coder metrics are not necessary to demonstrate the credibility of the research. Typically, credibility comes from the qualitative quality previously mentioned. Still, if catering to a more positivist/post-positivist audience or wanting to gain further insight into the data and coding scheme, the inter-coder metrics may assist the research team in agreeing on the categories in the coding scheme. In the interpretive lens, it is important and challenging for the multiple coders to have similar perceptions of how to view the data. There is inter-subjectivity – agreed or shared meanings between persons – that must be accounted for. For example, a poem can be read figuratively or literally, which changes the meaning of the poem. This is also evident in sarcastic or ironic commentary – should the commentary be taken literally then that changes the meaning. Therefore, when looking at the data, the multiple researchers need to take on the same interpretive perception of how to read the excerpts of the data. For the in-depth phenomenologically based interview methodology, it is not enough for the multiple researchers to read an excerpt of the data, since there can be a loss of context. The multiple researchers should read the three interviews of a single participant, begin a process of being trained in the coding scheme, and then code the ten-percent of the overall data corpus. Due to the nature of the presented methodology, the coding scheme (or typology) emerges from the in-depth phenomenologically based interviews, and then the coding scheme is used on the data of the second interviews as an a priori framework. Therefore, the overall data corpus includes only the data from the three-series interviews for the process of using the inter-coder metrics.

In order to gain inter-coder reliability or agreement, another coder has to examine ten-percent of the overall data corpus. It is suggested that the main researcher unitize this data and train the other coder on how to use the coding scheme (Campbell et al., 2013; Miles & Huberman, 1984). Then, the other coder codes unitized excerpts of the data (about 2-3 excerpts) and discusses the discrepancies with the interviewer. Once agreement is achieved, the coder proceeds to analyze ten-percent of the data, which the interviewer has already analyzed. Then the interviewer calculates inter-coder reliability with the coder, discusses discrepancies, and calculates the inter-coder agreement (Campbell et al., 2013). Through this, the interviewer and coder have established credibility for the coding scheme and resultant typology.

3.8 The Methodology in Practice

The phenomenologically based interviewing proves highly useful for exploring research questions seeking to understand a specific phenomenon that may be difficult to study, whether that be in regards to education, understudied or underrepresented populations, and complex phenomenon. For engineering design, this form of in-depth interviewing, when coupled with the analytical processes of grounded theory development, offers a robust methodology for uncovering the nuanced experiences of women students learning in a makerspace. More specifically looking at what types of learning women students are experiencing and how their design/learning pathways are developing.

Makerspaces are highly complex environments to study. While claims emphasize that makerspace are these open learning environments, there remains unspoken societal rules that assign gender to the making and designing of things (Meyer, 2018). Further, little empirical evidence exists that shows the value of making experiences and makerspaces for the professional development of STEM students in higher education. The lack of empirical evidence stems from the fact that these makerspaces are not the traditional classroom setting and are labeled as informal, interactive, collaborative, self-paced, and problem-based (Halverson & Sheridan, 2014; Lande & Jordan, 2014; Litts, 2015). These types of characteristics do not lend themselves well to controlled, quasi-experimental studies and show the need for a methodology that matches the complexity of these adaptive, dynamic, and interactive environments.

3.8.1 Interviewer

Described in Tomko et al. (2018b), the interviewer was a 25-year old woman graduate student studying mechanical engineering at a large public university in the South. She had received her Bachelors of Science degree in mechanical engineering at a northeastern public university. She was trained in qualitative and ethnographic methods from studying qualitative research for three years, taking a course on survey methodology and two courses on qualitative research methods, and working with three different qualitative researchers. In implementing qualitative methods, she employs an interpretive lens and also utilizes her youthful look (often being confused for a freshman) and her coy personality to incorporate ‘competent naivety.’ Her interest in making and makerspaces stems from her personal lack of hands-on experience and inability to physically build and solve open-ended, real-world problems. She is inspired by the woman engineering students who are making in makerspace and is intrigued by their stories.

3.8.2 Participants

Through purposeful maximum variation sampling and snowball sampling, the interviewer recruited women who were highly involved in making at the different university makerspaces. As highlighted in Tomko et al. (2018b), when studying women students who are highly involved in academic makerspaces, confounding factors play a role that makes it challenging to actualize the true population count: 1) incorrect labeling: women students may incorrectly label themselves as highly involved or not highly involved, and 2) different labeling: women students differ in what they label as a makerspace. For instance, a participant may label her major-specific studio building as a makerspace, but since it is not a common casual open space, then other students neglect to mention that studio building as a makerspace. While it may be challenging to affirm the true population size, the population of women who are highly involved in the university's makerspaces is visibly low. Therefore, it is important to seek saturation in the emerging interpretations of the data. In this study, five women students were recruited for the in-depth phenomenologically based interviews; then, fifteen women students were recruited for the single, targeted interview protocol. These women participants were at various academic levels, various majors, and had various interactions with the different spaces on the campus, as seen in Figure 9.

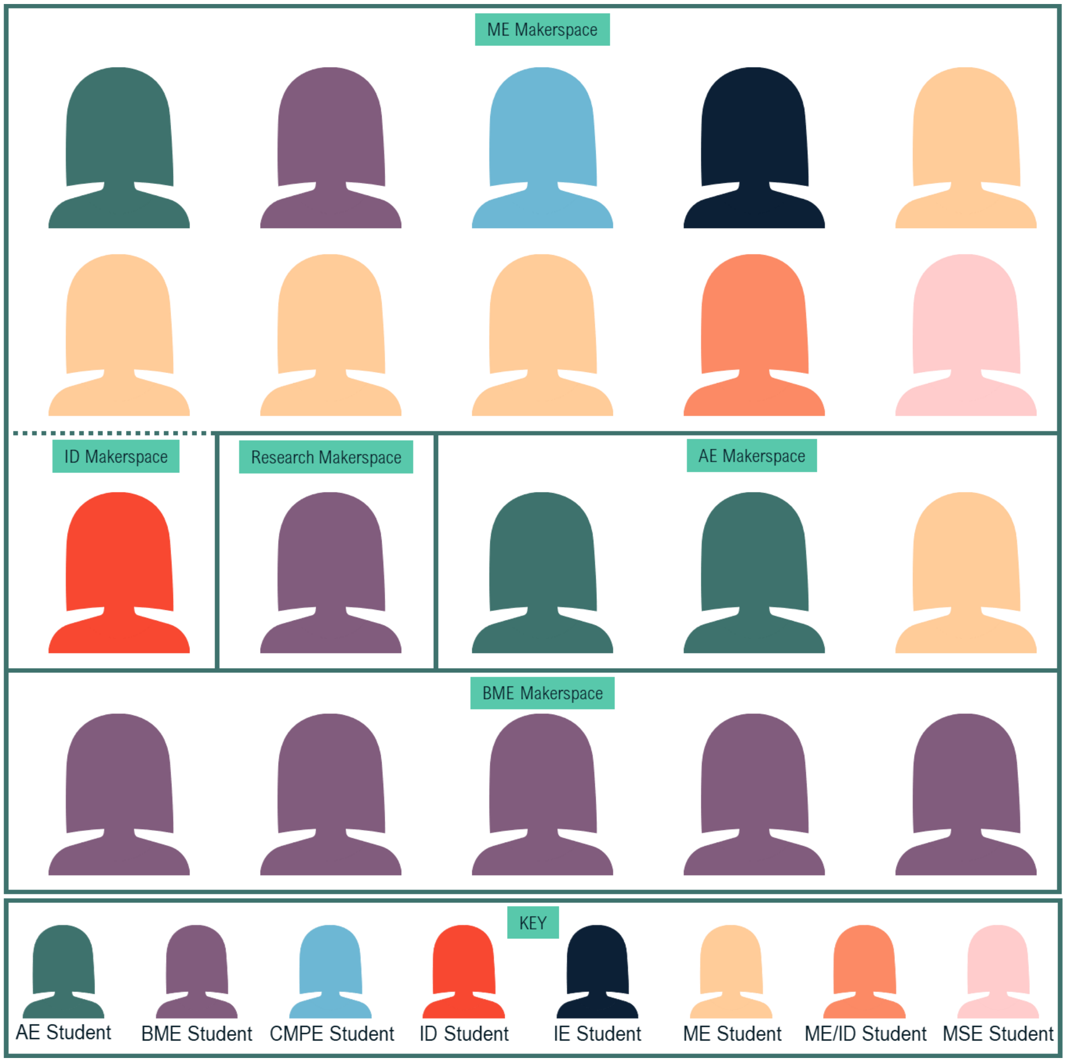

Figure 9: Participants' major and main makerspace involvement.

To maintain anonymity, the academic levels of the students have been omitted. While the women may have interacted with other spaces on campus, the figure addresses the spaces where they are most active. As such, it is interesting to note that the BME Makerspace has no variation in students, an ID student finds herself engaged in two makerspaces, the student involved in the graduate research makerspace is an undergraduate student, and the ME makerspace holds students of diverse majors.

3.8.3 *Interviewing Procedure*

The in-depth phenomenologically based interviewing process was conducted over the course of two months. To ensure little-to-no distractions, each interview was conducted in the same private room with the same experimental set-up. The interviewer took themes for each interview (life history, details of experience, and meaning) and generated a list of questions that would help guide the interview if needed. The questions were focused on helping the participant to craft their narrative around making and learning experiences, particularly in makerspaces; should interviewers create a list of questions, it is important to refrain from relying on the questions and neglecting to have a more natural conversation.

The second targeted interviews were conducted a year later, after the formation of the typology, and also over the course of two months. In this case, the interviewer used a semi-structured protocol with pre-determined questions derived from the typology. The interview used a timeline to start the interview as a means to examine how women students' design and learning pathways were changing over time and then provide a springboard for discussing how the participant's 'toolbox of design' changed from before being involved in the makerspace to their current involvement.

For both interviewing processes, the interviews were audio-recorded, as authorized by the participant's consent. After each interview, the audio recordings were uploaded to the computer, edited to remove extremely confidential information along with superfluous banter at the beginning and end of the interview, and then outsourced to be transcribed. In order to check the accuracy of the transcripts, the researcher listened to each interview and corrected any errors and incorporated untranscribed utterances that the transcriber failed to capture. The first set of in-depth interviews resulted in 463 pages of single-spaced transcriptions, and the second set of targeted interviews resulted in 405 pages of single-spaces transcriptions.

3.8.4 Data Analysis

The qualitative data analysis process is time-consuming and extremely iterative. To demonstrate the rigor and intensity, the data analysis process used for studying how makerspaces support women in makerspaces is described in detail. These are the steps implemented for generating a coherent typology. The steps are separated into multiple phases (see Figure 10):

1) the first phase corresponds to establishing a coherent foundation for the coding scheme

2) the second phase corresponds to refining the coding scheme such that a typology of learning experiences can be described

3) the third phase corresponds to examining the coding scheme in relation to existing literature and towards showcasing credibility

4) the fourth phase corresponds to engaging the coding scheme with all of the data

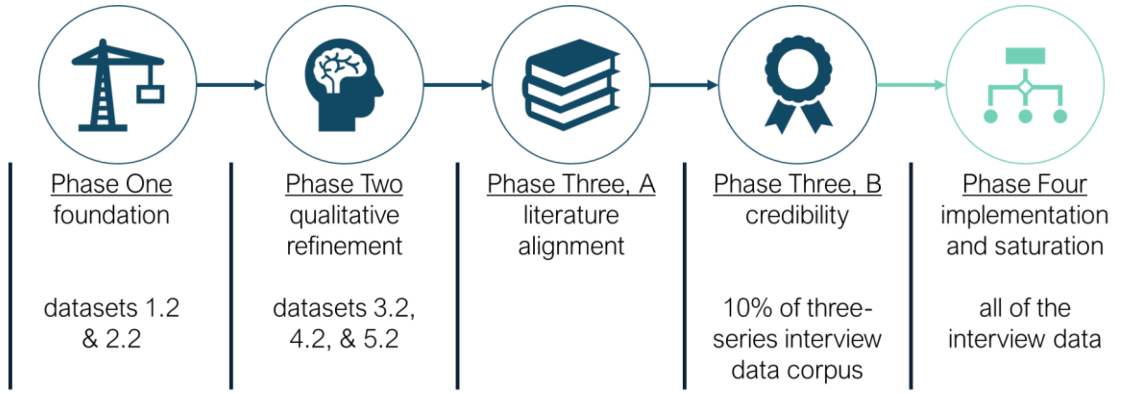

Figure 10: Process for data analysis.

Various researchers participated in the different phases of the analysis process. For this study, the main researcher is also the interviewer and is considered the expert on the material since she developed the research protocol, conducted the interviews, and is immersed in the data. Besides the interviewer, there was an undergraduate researcher (UGR), three engineering design faculty researchers (edFR-1, edFR-2, edFR-3), a psychology graduate student (PGR), and two qualitative faculty researchers (qFR-1, qFR-2) involved throughout the process. Not all researchers participated were engaged in every phase, because of availability or changes in personnel involved in the project. All researchers had localized training from one of the qualitative researchers.

In phase one and phase two, the research team focused on the second interviews of the participants involved in the in-depth phenomenologically based interviewing process. The label “dataset 1.2” corresponds to the second interview of the first participant, the label “dataset 2.2” corresponds to the second interview of the second participant, and so forth until the fifth participant. For phase three, the research team used the third interviews of the participants involved in the in-depth phenomenologically based interviewing process.

Then, all of the data from both the in-depth interviews and the single, targeted interviews are used.

3.8.4.1 Phase One

In Phase One of data analysis, the team aimed to create a coherent, foundational coding scheme toward the construction of a typology of learning experiences of women makers. The team engaged first in a process to decipher initial insights in the data. Then the team created a coding scheme from analysis of the dataset 1.2. Further, the team expanded the coding scheme via analyzing the dataset 2.2 and using inter-coder metrics to gain further insights into the data and coding scheme.

Step One – Initial Insights. First, in order to get a sense of the data and identify the emergent categories of learning, the interviewer immersed herself in the data, by reading datasets 1.2 and 2.2 several times. Second, she began the process of open coding. In this case, open coding seeks to answer the question "what is this participant learning?" (Tomko et al., 2018a). Open coding is the process of line-by-line constant comparison in which the interviewer identifies attributes and dimensions of learning. Initial open codes included attributes such as, "patience," "communicate ideas," and "problem solve." After open coding the datasets 1.2 and 2.2, the interviewer grouped the dimensions and attributes into relational categories through the processes of axial coding, seeking to group the open codes into qualitatively similar types of learning. Following this initial coding of the data, the interviewer, the dFR-1, and the qFR-1 then independently reviewed a sample of the dataset 1.2 (approximately ten-percent of dataset one, as suggested by Campbell et al. (2013); the three researchers discussed the emergent codes (categories of learning) through a series of peer debriefing sessions. The purpose of this step is to determine whether the emergent codes were fully addressing the research question and thus led to the additional focus on the *processes* of learning that are also important to the inquiry.

Step Two – Dataset 1.2 Revisited. Amidst the initial insights and better understanding of the focus for inquiry, the interviewer and the UGR independently created open codes for the dataset 1.2, in its entirety, while focusing on the question "*how* is one learning in a makerspace?" This second round of coding served to open up the data further to add to the existing codes developed in Step One. The interviewer and the UGR met to discuss the emergent codes and the points of conflict in coding. After resolving the points of conflict, the interviewer consolidated the open codes and organized them into categories of learning through axial coding in order to develop an initial coding scheme, based on the first dataset.

Then, the interviewer unitized a sample of dataset 1.2 by units of meaning (Campbell et al., 2013) and separately trained the UGR and qFR-1 on using the coding scheme to code the sample of unitized data. By having multiple researchers to use the coding scheme to look at the same sample of the data, additional insights into the codes and the coders' discrepancies were illuminated so as to further edit and improve the coding scheme and analytical process that would be used on additional datasets. This process yielded insights regarding both the clarity and complexity of the coding scheme. For example, this process showcased that the UGR and qFR-1 were able to identify broad categories of learning in the data, such as "learning by doing," but were not consistently able to identify the specific types of learning by doing. This training and coding process indicated that there was agreement regarding what kinds of learning were emerging from the data, but revealed the coding scheme as overly complex and requiring greater definitions and specific coding rules to mark qualitative distinctions between the subcategories of types of learning.

Step Three – Dataset 2.2 Revisited. In efforts to continue developing the coding scheme, the UGR and interviewer turned to open-code dataset 2.2, building from the coding scheme refined in Step Two. Independently, the UGR and interviewer consolidated their codes; then, they met to discuss the new codes that emerged, the coding scheme, and the challenges faced in trying to code the data. This discussion illuminated points of ambiguity in the coding definitions along with the need to both collapse and refine some categories in the coding scheme so as to create clearer qualitative distinctions between categories. As a result, the interviewer refined the coding scheme into a primary and secondary structure, in order to create a coding scheme with a simpler structure.

After refining the coding scheme and re-unitizing the sample of data, the interviewer trained the UGR and edFR-1 in the revised coding scheme, and they coded a subset of dataset 2.2. Following the coding process, they reviewed the agreements and discrepancies in coding to continue the process of refinement. As in Step Two, this process illuminated further areas that need greater clarity of definition, as well as affirmed the credibility of the emergent codes. Following this, the UGR and interviewer participated in a series of peer debriefing sessions to review the data, discuss discrepancies in codes, and negotiate agreement. Through negotiating agreement, the interviewer and UGR increased the percent inter-coder reliability of 0.47 to an inter-coder agreement of 0.96, which were calculated using the process described by Miles and Huberman (1984, p. 63) and involves dividing "the number of coding agreements by the number of agreements and disagreements combined" (Campbell et al., 2013, p. 309). This discussion identified areas of overlap in the codes, along with a need for a more thorough training process. To help reconcile ambiguity, the interviewer refined and revised the coding scheme to include examples from the data for each of the codes. This process created the foundation and resulted in the final first reconciled version of the coding scheme.

3.8.4.2 Phase Two

While the foundation for the coding scheme was established, the iterative qualitative data analysis process proceeded to refine the coding scheme through coding the other datasets (second interviews), developing clear coding instructions for analysis of future datasets, and incorporating additional researchers/coders: edFR-2 and qFR-2. The process for refining the coding scheme and creating clear coding instructions included the UGR and interviewer as well.

Step One – Remainder Datasets. The interviewer and the UGR read and analyzed the remainder of the second interviews (3.2, 4.2, and 5.2). Using different approaches, the interviewer proceeded to open-code the remainder datasets while the UGR specifically looked for gaps in the coding scheme. Upon reading through the datasets, the UGR informed and discussed the gaps with the interviewer; it was evident that the gaps were related to the need to further clarify the definitions of the codes. To achieve greater clarity, the interviewer invited additional perspectives to examine the coding scheme and datasets.

Step Two – Qualitative Refinement. The interviewer and qFR-2 worked together in order to refine the coding scheme and coding instructions. Upon reviewing all of the second interviews and the coding scheme, the interviewer and qFR-2 met to discuss the areas of contention, the instances of confusion, and the repetition of codes across all five datasets. The qFR-2 asked pointed questions that invited distinction between categories of learning. This led to the creation of a series of coding rules for each category. A coding rule instructs the interviewer (or other person coding the data) on those inclusion and exclusion criteria that would lead to labeling a unit of analysis with that code. This becomes particularly important toward making claims about the qualitatively different kinds of learning experienced. For example, there are numerous types of 'learning by doing' identified in the data, and each may have different implications for the learner. Thus, offering meaningful distinctions between each of those types is not only important for coding future data but is also important toward the description of a meaningful typology of learning that yields both theoretical and practical implications.

As a result of this refinement process, a comprehensive codebook was established that included for each code: a number, a name, a description, an example, and a set of coding rules. From there, the interviewer and qFR-2 immersed in the data and the codes for a prolonged period of time, in this case two weeks, in order to restructure the coding scheme, tighten the definitions, and articulate coding rules and instructions. During this time, additional insights were provided by other uninvested colleagues so as to ensure that everything in the coding scheme made sense. This commitment to continuous peer debriefing led to a coherent refined coding scheme and clear coding instructions for potential future datasets. The development of a robust codebook is critical to coding large volumes of data dependably, particularly when multiple researchers are collaborating, and enables the continued refinement and testing of codes through each iteration of data analysis.

Step Three – Training & Modifications. In the training process, the interviewer and qFR-2 presented and discussed the coding scheme with the edFR-2, and then examined a sample of the data together. Because the edFR-2 was not familiar with the coding scheme, the team was able to evaluate if the categories in the coding scheme were clearly described, qualitatively distinct from one another, and identifiable in a subset of the data. This process illuminated areas in the coding scheme that required greater clarity in the definitions and the establishment of additional coding rules that clarify exemplars of learning in this and future datasets.

Then, the edFR-2 was given two small excerpts from the data that were unitized by the interviewer. These excerpts were a little more than half a page. The edFR-2 coded the two excerpts and then returned to discuss the discrepancies with the interviewer and qualitative researcher. In the first excerpt, the inter-coder reliability was high, but in the second excerpt the inter-coder reliability was very low. Through the discussion, it became clear that the interviewer and edFR-2's perceptions of the data impacted their interpretation and codes of the data. For example, in the first excerpt the edFR-2 determined that the excerpt was about the design process, which was the same perception as the interviewer. However, for the second excerpt, the edFR-2 read the excerpt to be about social communication, whereas the interviewer had known it to be about learning by failing. Over the course of a lengthy discussion, the team realized the need to acquire context and have similar perceptions of the data, in order to allow for inter-coder credibility.

3.8.4.3 Phase Three

For phase three, the research team enhances the coding scheme by gaining insights from an additional engineering design researcher (edFR-3), exploring connections to existing literature and frameworks, examining the third interviews of the participants involved in the in-depth phenomenologically based interviewing process, and training a psychology graduate researcher (PGR) on the coding scheme.

Step One – Peer Debrief. In efforts to ensure the typology would align with an engineering design audience, the research team invited the edFR-3 to participate in a peer debriefing session. Since the edFR-3 was not involved to this point, the edFR-3 would be able to provide unique and unbiased insights about the coding scheme. In the peer debriefing session, the interviewer, the edFR-1, the qFR-1, and the edFR-3 met to discuss the ways in which the coding scheme would align or not align with the engineering design audience. The discussion brought forth concerns where participant's voices and word choices being used as 'types' in the typology might not align with the literature. For example, participants used "problem-solving" to describe their way of thinking through the design process. Using "problem-solving" in the typology contradicts with the literature on problem-solving, which focuses on more controlled studies where participants solve brainteaser-like problems. This led to the decision for the interviewer to examine the literature and existing frameworks in order to gauge connection and alignment, particularly for the engineering design process.

Step Two – Literature Alignment. The interviewer examined the literature on problem-solving, the design process, design thinking (Brown, 2008), Bloom's taxonomy

(Bloom et al., 1956; *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*, 2001), and 21st century skills (cognitive, interpersonal, intrapersonal) (NRC, 2012), among other learning frameworks (Adams et al., 2011; Greeno et al., 1996; Kolb, 1984; Leonard, 2002). Ultimately, efforts to try and tie in the various frameworks led to reconfiguring the coding scheme towards the cognitive, interpersonal, and intrapersonal categories. In this process, the interviewer tightened the language, definitions, rules, and labels for each of the codes. This coding scheme was used to devise the interview questions for the single, targeted interview.

Step Three – Training and Inter-Coder Credibility. To gauge the credibility of the coding scheme, the interviewer needed to train another coder (the PGR) on the coding scheme. The PGR had been trained in qualitative methods and the presented methodology under the oversight of the edFR-2 and qFR-2. First, for training, the PGR read the three interviews of a single participant, randomly selected by the interviewer; meanwhile, using the primary codes, the interviewer unitized and coded 45 pages of those three interviews (roughly ten-percent of the overall three-series interview data corpus). Second, provided with the unitized data, the PGR and the edFR-2 met with the interviewer; the edFR-2 was involved as a mediator so as to provide clarification as needed. The interviewer and edFR-2 reviewed the coding scheme with the PGR in order to ensure that the PGR fully understood the coding scheme. Third, the PGR and interviewer discussed the first few excerpts of the data, and then the PGR separately analyzed the rest of the unitized data. Fourth, the interviewer calculated inter-coder reliability using Cohen's Kappa, discussed discrepancies with the PGR, and calculated inter-coder agreement using Cohen's Kappa.

3.8.4.4 Phase Four

After making slight refinements to the coding scheme after phase three, the interviewer used the final coding scheme to code all of the data, which at this point included both the in-depth phenomenologically based interview data and the single, targeted interview data. Overall, the data analysis process involved a year-and-a-half worth of time. The inter-coder metrics and the finalized typology of learning will be discussed together in detail in the next chapter.

3.8.5 A Typology of Learning

Data analysis of the interviews yielded a typology of learning for women in a makerspace at a large public institution in the south. The typology showcases the types of learning associated with women students in academic makerspaces. This includes the modes of learning and the products of learning (the cognitive skills, interpersonal skills, and intrapersonal skills). Evidenced by the overarching categories (Table 1), the typology of learning demonstrates that a makerspace supports more than the learning of just tools and machines. The learning that a makerspace supports has more breadth and depth. By using the phenomenologically based interview process, we were able to generate a detailed and robust typology.

Table 1: Typology at a glance: the primary and secondary categorization.

1	**LEARNING BY DOING**
1.1	Failing
1.2	Struggling
1.3	Practicing
1.4	Iterating
1.5	Exploring
2	**LEARNING THROUGH OTHERS/ COMMUNICATING & MANAGING**
2.1	Observing and Listening
2.2	Collaborating or Working with others
2.3	Receiving or soliciting help
2.4	Giving help or instruction
2.5	Leading or Administering
3	**CONTENT KNOWLEDGE AND SKILLS**
3.1	Design
3.2	Manufacturing and Tools
3.3	Computational Tools
3.4	Materials
4	**CULTURAL KNOWLEDGE AND SKILLS**
4.1	Access conventions and protocols
4.2	Roles and structure of participation
4.3	Rules of the community
4.4	Gender associations
5	**INGENUITY**
5.1	Improvisation
5.2	Opportunism
5.3	Resourcefulness
6	**SELF AWARENESS**
6.1	Confidence
6.2	Patience
6.3	Resilience
6.4	Reflective

3.8.6 Design and Learning Pathways

Alternatively, the phenomenologically based interviewing approach described in this dissertation offers the ability to explore more than types of learning. Certainly, building off of the work of generating the typology and coupling the narratives and timelines from the interviews, we can begin to examine how women student's design and learning pathways are developing. The women student narratives and timelines can be analyzed with similar grounded theory analysis techniques, where each woman's narrative and timeline are compared in order to identify emerging themes and patterns. From these emerging themes and patterns, we can begin to understand questions of how these women enter spaces, does a making background impact involvement in the space, what are the barriers to entry, and are there gendered experiences that impact a woman's involvement. These types of questions are difficult to answer with quantitative means, which are challenged in extracting stories of underrepresented student populations in engineering design. Whereas, the methodology presented in this dissertation is particularly useful for generating insights for engaging women in engineering design.

3.9 Conclusions

This chapter emphasizes the importance of qualitative techniques and how the specified qualitative approaches can be appropriately applied in engineering design as a means to obtain deeper insights. When describing the phenomenologically based interviewing methodology, we highlight the critical aspects, such as interviewer-participant relationship or recruiting strategies that impact the quality of the interview data. Ultimately, this interview methodology is highly effective when interviewers and researchers take the time to consider the research questions, scope, and culture of study. Through both the in-depth three-series interviewing and the single targeted interview, the participants share their narrative of experiences, as pertaining to a certain phenomenon. As such, a greater sense of trust, rigor, and credibility result. To demonstrate, this chapter presents the "methodology in practice" in order to illustrate the processes for implementing the interviewing methodology and analyzing the data for how academic makerspaces support learning of women students. This work designates the approach for developing a thorough and rigorous coding scheme that lends way to a complete typology; similarly, this approach could be used in other research directions so as to develop typologies for prototyping, design methods, design projects, engineering trajectories, or product development. Overall, this chapter forwards a qualitative methodology novel to engineering design research – phenomenologically based interviewing – and presents the qualitative methodology as a roadmap for engineering design researchers.

CHAPTER 4. LEARNING IN MAKERSPACES

Developing a learning model for how women students tap into their "toolbox of design."

4.1 Research Question to be Addressed

Learning in engineering design emphasizes hands-on, real-world experiences that engage critical thinking, problem-solving, and iterating through the design process. While advances have been made in studying the learning in engineering design in the classroom, challenges persist in efforts to study the hands-on, real-world experiences occurring in university makerspaces. This chapter forwards the efforts to understand the learning for women students by the following research questions:

- **(RQ1a)**: what are the different types of design competencies and learning types that are reported by women in an academic makerspace?
- **(RQ1b):** how are women students' design and learning competencies interacting and developing?

These questions are answered by using the methodology described in the previous chapter, where the "methodology in practice" example corresponds to the data collection and analysis strategies of this chapter and the next chapter. However, the previous chapter gave a thorough overarching account; therefore, we provide a contextualized summary of the methodology and methods that forward the analysis of design and learning in this chapter and then pathways in the next chapter.

Through investigating how university makerspaces support women students learning along with their engagement in engineering design, we articulated the types of learning (both modes of learning and products of learning) that women students engage in, the themes of learning and design that recur in women student narratives, and the interaction between the types of learning (represented by a learning model).

The three-series in-depth interviews were analyzed using grounded theory techniques and coding methods as a means to develop the typology. The typology is described in detail. We further analyzed for common themes and patterns among the data and identified that makerspaces act as an "environment of everybody is learning," as a "design journey," and as a "laboratory for creativity." Then, we created a learning model that showcases how design and learning interact in the makerspace. Thereby, makerspaces are confirmed to help provide women students with a diverse skillset, that engages design, manufacturing, cultural knowledge, failure, collaboration, confidence, resilience, communication, management, and ingenuity

4.2 Summary of Methodology & Methods

In this study, we adopted and adapted the interviewing process described as the in-depth phenomenologically based interviewing process (Seidman, 2006). This process utilizes life history interviewing (Bertaux, 1981) with in-depth interviewing that is based in the phenomenology of Alfred Schutz (1967). In the process described by Seidman (2006), participants engage in a three-series interview process, where each interview is 90-minutes in duration. The process focuses each interview on a different topic as a means to understand the participant's lived experiences of a phenomenon of interest (in this case learning in makerspaces). The first interview seeks to understand the participant's past experiences associated with learning through making. The second interview seeks to understand the details of the participant's experiences making in the makerspace(s). The third interview seeks to understand the meaning of the participant's involvement in the makerspace(s).

Since engineering design focuses on creating a design through a process, we innovated the methodology in two ways: 1) for the second interview, participants were asked to bring an artifact with them – a project that they made, and 2) for the third interview, participants were asked to draw out a timeline of their making experiences leading up to their involvement in the makerspace. In the first innovation for the second interview, the artifact provided a starting point for the conversation and allowed participants to tangibly walk through their design process (Figure 11) shows the types of projects a student might talk about). In the second innovation for the third interview, the timeline also provided a starting point and allowed a means of reflection for the participants. Examples of recreated and de-identified timelines are found in the next chapter (Figures 15-17).

To again adapt the methodology for the purposes of engineering design, we implemented an additional interview protocol. After a year of data collection and data analysis of the interviews from the in-depth phenomenologically based interviewing process, we created a targeted, focused, single interview protocol that would be roughly 60-90 minutes in duration. The interview questions of this protocol were developed from the learning typology that evolved out analyzing the in-depth three-series interview data. The purpose of the single, targeted interview protocol was to confirm the findings from the in-depth three-series interviews and to be able to engage a greater number of participants in the overall study, producing a sample size more appropriate in engineering design studies.

Figure 11: Types of projects that might be brought in for the second interview.

4.2.1 *The Participants*

Overall, twenty women participated in the study: five in the in-depth three-series interviews and fifteen for the single, targeted interview. These women students were recruited and selected via purposeful maximum variation sampling and snowball sampling (Morgan, 2008). By implementing purposeful sampling, we selected students based on their potential to provide detailed and thorough information towards learning in makerspaces, given the resources available (Palinkas et al., 2015; Patton, 2002). Then, students were further selected based on their ability to truly represent the larger population, also known as maximum variation sampling (Seidman, 2006; Tagg, 1985). Through maximum variation sampling, a wide range of perspectives and variation are sought out as a means to create larger reliability to a greater audience. For this study, purposeful sampling captured women students who were highly involved in a makerspace on campus. The introduction to these types of women was facilitated by word of mouth (snowball sampling). To ensure maximum variation, we mainly targeted three main makerspaces on campus for initial recruitment, which lead to recruiting women of various majors, academic levels, and backgrounds.

4.2.2 *The Interviewer*

The type of interviewing used in this study is characterized by delving into the lived experiences of women students through a dialogue between the interviewer and the participant. The interviewer's demeanor and interpretation of questions impact the conversation and thus, the data. In this study, the interviewer was a woman graduate student in her mid-twenties studying mechanical engineering at a public university in the South.

Her undergraduate degree was also in mechanical engineering, and she had a youthful look that allowed people to mistake her for a first-year student and be more willing to divulge their knowledge to her. She had three years of studying qualitative methods and utilizes an interpretive lens due to the need to engage women students' interpretations of making in makerspaces.

4.2.3 The Interview Procedure

The first round of interviews was conducted over the course of two months in the Fall 2017 semester. After rigorous data analysis, we created a concise semi-structured interview protocol and conducted interviews at the end of the Fall 2018 semester and the beginning of the Spring 2019 semester. For both rounds of interviews, the interview questions were based in the themes of life history, details of experience, and meaning (see Appendix A-B for questions). After each interview, the interviewer uploaded the audio recording to a computer, removed superfluous banter, outsourced the audio file to be transcribed, and then edited transcriptions for missed jargon and for removing confidential information. This resulted in a total of 868 pages of single-spaced transcriptions.

4.2.4 The Data Analysis

Once the first interview was completed and transcribed, we began the qualitative data analysis process, which is iterative and includes multiple phases. In this process, the interviewer immersed herself in the data and used the constant comparison method for understanding the data. Through constant comparison, the interviewer would examine, analyze, and compare each interview as a means to further inform the steps for data collection and analysis. The interviewer continued conducting interviews until reaching theoretical saturation, or no new themes were emerging from the data (Douglas, 1976; Glaser & Strauss, 1967; Tracy, 2013). In analyzing the data, the interviewer utilized multiple cycles of coding (open and axial coding) with various researchers and numerous peer debriefing sessions. The coding process resulted in the construction of a typology for learning in makerspaces.

This typology was created from the in-depth phenomenologically based interviewing data. The typology included a label, a definition, coding rules, and examples for each category, where categories were arranged into primary and secondary codes. For example, 'learning by doing' was a primary category with secondary codes of 'failing,' 'struggling,' 'practicing,' 'iterating,' and 'exploring' (see Table 2 for an example).

Table 2: The 'learning by doing' category in the typology.

ID	Code	Description	Coding Rules	Example
1	**LEARNING BY DOING**	Discussion of learning by doing - learning through experiences as a direct result of one's own actions.	Code when participant uses words such as "hands-on" or "hands-on learning," "need to do it," "need to make it." Reflects the concept "If I do it, I know it." *This code can be by itself or paired with the codes below. "Trial-and-error" is also a cue and could be a cue for any code below.*	Like I'm very hands-on. I have -- to learn something, I have to do it.
1.1	Failing	Discussion of failing, making mistakes, falling short in succeeding to achieve a goal, or to error in one's action or judgment.	Code when participant points to specific mistakes or failures they made that required them to rethink *how* they were making. Mistakes might be related to the choice of machine, the speed, the steps, or the materials.	And so I went in and I'm like, "Okay, so let me just take this wood and cut it down." And I cracked a piece of wood. And I'm like, "Shoot, okay, I can't do it this fast."

Table 2 Continued.

1.2	Struggling	Discussion of working through a task or contending with a task while having uncertainties.	Code when participant says things like "I didn't know how" or "I didn't understand at first," as well as "overcome," "struggle," "difficulty." This is distinct from 1.1 in that there is a focus on obstacles such as lack of knowledge that must be worked through, whereas 1.1 points to specific failures and mistakes that needed correction.	But in you struggling through like, "Let me try this formula. Seems like the units work out." … Versus me accidentally picking the right equation and plugging it in, it working, I might not be able to recreate that on the test, you know. That same idea or concept is how like I think I've learned through design
1.3	Practicing	Discussion of experimenting in order to gain proficiency. The participant is practicing with tools, machines, software, or material; making projects in order to get the hang of how a tool, machine, etc. works or how to make something.	Code when participant indicates that they have followed the <u>same</u> process over and over again. Words like "perfecting," "getting better at it," might appear in this code. Also "play around" is a cue for both 1.3 and 1.5 - the difference is that in 1.3, the person is trying to gain proficiency and in 1.5 the person is trying to figure out a solution.	Like once you've made something four or five times, you're fast, you're good at making it. You know all the shortcuts. You know where it's going to give you trouble.
1.4	Iterating	Discussion of intentionally experimenting to get something right; making something over again or repeatedly.	Code when participant uses sign-posting such as "first time" or "first try," followed by "second time" This code is distinguished by each "try" reflecting a <u>change in the process or design,</u> whereas 1.3 is just repetition of the same process.	But I made -- like the first one, it was too big. And the second one, the engraving didn't come out really well. But about the fourth one, I realized I had misspelled [something]. I did all those iterations.

Table 2 Continued.

1.5	Exploring	Discussion of experimenting to figure out a solution or something that works through exploring, tinkering, playing around, or fixing; not having a direct plan.	Code when participant describes a process that has no clear path. Phrases like "you've just got to play around with the settings" or "just do it and see what happens."	That's how usually I learn. I'm like, oh, that's cool, let me see if I can do that, and then I try it. And then I'm like, okay, I can't do it this way, but then I figure out a way around it to do what I want it to do, if that makes sense?

To ensure the rigor of the typology, efforts were made to attain inter-coder reliability on the typology on the primary categories. First, the interviewer randomly selected a random participant's dataset and had another researcher read through the entirety of the dataset. Then, using the primary categories, the interviewer coded and unitized ten-percent of the overall data corpus (meaning only the in-depth interviewing data at this point) using NVIVO Software. The interviewer then trained the other researcher in using the typology as a means to code the data. The interviewer and other researcher went through a few excerpts in the data; this was in efforts to confirm that the other researcher had an understanding of the process and would use the same interpretive lens for analyzing the data. Once the other researcher seemed to have a handle on the typology and the data, the training session ended and the other researcher finished coding the ten-percent. After the other researcher finished analyzing the ten-percent, the interviewer calculated inter-coder reliability on the ten-percent that the other researcher coded after the training session. From using Cohen's Kappa analysis, the inter-coder reliability resulted in agreement of 0.70, with a percent agreement of 75.8 (see Appendix C for calculation). For comparison purposes, the NVIVO Software also calculates inter-coder reliability using the agreement of characters; in the NVIVO analysis, the Cohen's Kappa was 0.78 and percent agreement was 95.85 (see Appendix D for calculation); however, the NVIVO calculation includes the few excerpts that were used to confirm the other researcher's understanding of the process.

Then, the interviewer discussed discrepancies with the other researcher and calculated inter-coder agreement. Through reconciling discrepancies and discussing the data, the interviewer and other researcher came to agree on all the unitized data, resulting in an inter-coder agreement value of 1.0 Cohen's Kappa and 100% agreement. This demonstrates the credibility and rigor of the typology.

4.3 The Typology

The typology showcases the breadth and arrangement of categories associated with the women's experiences learning in the makerspace. In this arrangement, categories are characterized by modes of learning and products of learning, where products of learning are further categorized by cognitive competencies, interpersonal competencies, and intrapersonal competencies (see Appendix E-G for iterations of the typology and Table 3 for the full typology). Modes of learning refer to the ways in which women students refer to *how* they are learning. Products of learning describe *what* women students are learning from their involvement in the makerspace. Cognitive competencies are the types of knowledge that women students gain. Interpersonal competencies correspond to the social skills that women students have acquired from their involvement in the makerspace. Lastly, the intrapersonal competencies are the women's internal skills and awareness that have evolved from the activities and social interactions within making and the makerspace.

Collectively, the categories capture both how and what women students learn from makerspaces.

Table 3: The full learning typology.

	ID	Code	Description	Coding Rules	Examples	
Mode of Learning	**1**	**LEARNING BY DOING**	Discussion of learning by doing - learning through experiences as a direct result of one's own actions.	Code when participant uses words such as "hands-on" or "hands-on learning," "need to do it," "need to make it." Reflects the concept "If I do it, I know it." *This code can be by itself or paired with the codes below. "Trial-and-error" is also a cue and could be a cue for any code below.*	Like I'm very hands-on. I have -- to learn something, I have to do it.	Because I'm a very like tangible object person. So I'm like, "All right, I'm going to go to Home Depot. I'll be back in 15 minutes with a wooden dowel, and we'll chop it up, and we'll just try it," because like a lot of groups had problems of where we were taught to like draw out all of our concepts. And I was like, "Let's just do it. Let's build something.
	1.1	Failing	Discussion of failing, making mistakes, falling short in succeeding to achieve a goal, or to error in one's action or judgment.	Code when participant points to specific mistakes or failures they made that required them to rethink *how* they were making. Mistakes might be related to the choice of machine, the speed, the steps, or the materials.	And so I went in and I'm like, "Okay, so let me just take this wood and cut it down." And I cracked a piece of wood. And I'm like, "Shoot, okay, I can't do it this fast."	That's how usually I learn. I'm like, oh, that's cool, let me see if I can do that and then I try it. And then I'm like, okay, I can't do it this way, but then I figure out a way around it to do what I want it to do, if that makes sense?
	1.2	Struggling	Discussion of working through a task or contending with a task while having uncertainties.	Code when participant says things like "I didn't know how" or "I didn't understand at first," as well as "overcome," "struggle," "difficulty." This is distinct from 1.1 in that there is a focus on obstacles such as lack of knowledge that must be worked through, whereas 1.1 points to specific failures and mistakes that needed correction.	And so after I laser cut them I realized I need to have this bolted, so I put the bolt in there and then I was talking to Blake in the shop and he was like, oh, why don't you just drill down, invert the drill or drill down so that there's a hole, drill a hole, tap it. I was like, oh, I don't know how to drill and tap some things, and so he showed me how to drill and tap some things. So I did that for that. And then I ended up making a bunch of skegs for the team, yeah. So just through needing something and then like making it.	I just hand you the book, I'm like open-book, have fun, and I give you like a problem, you would struggle through it for like some time, right? But in you struggling through like, "Let me try this formula. Seems like the units work out." In you doing that, and being like, "Oh, shit. That's not the right one. Why isn't it? Oh, it's because I'm considering the velocity in the wrong direction." Or like of that way of learning, you will like actually learn how the equation works. Versus me accidentally picking the right equation and plugging it in, it working, I might not be able to recreate that on the test, you know. That same idea or concept is how like I think I've learned through design.
	1.3	Practicing	Discussion of experimenting in order to gain proficiency. The participant is practicing with tools, machines, software, or material; making projects in order to get the hang of how a tool, machine, etc. works or how to make something.	Code when participant indicates that they have followed the same process over and over again. Words like "perfecting," "getting better at it," might appear in this code. Also "play around" is a cue for both 1.3 and 1.5 - the difference is that in 1.3, the person is trying to gain proficiency and in 1.5 the person is trying to figure out a solution.	Like once you've made something four or five times, you're fast, you're good at making it. You know all the shortcuts. You know where it's going to give you trouble.	And then so I ended up designing a bunch of them and laser cutting a bunch of them and that's how I became more proficient I guess on the laser cutter.
	1.4	Iterating	Discussion of intentionally experimenting to get something right; making something over again or repeatedly.	Code when participant uses sign-posting such as "first time" or "first try," followed by "second time" This code is distinguished by each "try" reflecting a change in the process or design, whereas 1.3 is just repetition of the same process.	But I made -- like the first one, it was too big. And the second one, the engraving didn't come out really well. But about the fourth one, I realized I had misspelled [something]. I did all those iterations.	So we were playing with the different angles and we did like the 45, made the 90 and then we found the -- we tried a 30 and then that worked pretty well but it was still kind of weird looking because it kind of was trying to make a circle. And then I think we ended up going with 12.5 because it was a little less than 15. Because we didn't want one that would end up summing to be a 90 eventually, right? So it was just through taking a dowel, cutting it at a bunch of different angles, and then seeing which angle we could make into this U-shape that would fit around a muscle. So it was a bunch of trial and error that we did at the BME machine shop.
	1.5	Exploring	Discussion of experimenting to figure out a solution or something that works through exploring, tinkering, playing around, or fixing; not having a direct plan.	Code when participant describes a process that has no clear path. Phrases like "you've just got to play around with the settings" or "just do it and see what happens."	That's how usually I learn. I'm like, oh, that's cool, let me see if I can do that and then I try it. And then I'm like, okay, I can't do it this way, but then I figure out a way around it to do what I want it to do, if that makes sense?	And then we were like on the lathe, we can also cut a notch so that this isn't a heavy right angle, so that it'll give us more curve. So we started doing stuff like that and playing around with the machine shop. And we ended up coming up with a final product that works pretty well.

Table 3 Continued.

Mode of Learning AND Product of Learning: Interpersonal	**2**	**LEARNING THROUGH OTHERS/ COMMUNICATING & MANAGING**	Discussion of seeing what other people are doing or interacting with other people as a way to beget more understanding of something.	Code when participant discusses the importance of being present in the environment to learn and talking with other people. Words like "hanging out," "spending time" might appear in this code. *This code can be by itself or paired with the codes below.*	How to communication-- definitely, like, graphic communication's gotten ton better.	Like, when I go in, I'll look for my friends and we'll just, like, have a conversation, just like, what are you making, what are you working on? It's like, having the environment where it seems like people are, like, happy to be there and enthusiastic, and, like, want to talk about what they're doing and share what they're doing.
	2.1	Observing/ Communicating - Listening	Discussion of watching what someone is doing or saying and then realizing how one can use those insights in their own work.	Code when participant uses words like "observing," "seeing what others are doing," "listening," "learning from watching." This code can be linked with training (2.4) as someone watches an instructor and is told how to achieve a task.	"Why don't I go hang out there and see what I can do with my project," I think is a lot of what happens. Which is pretty cool of like it's not something you think about, but I think it's something that I've observed, that it's very cool.	Or like I was always laser cutting flat things, and then I saw someone take something flat, make it 3D. And I was like, "Wow! I could use that same machine, cut out pieces that fit together like a jigsaw puzzle." It makes sense, and it clicks once I've seen it happen. And then I'm like, "Okay, now I can like make 3D things out of flat acrylic pieces that I cut." And then I like will make something 3D and be like, "All right, this is cool. I can like start using this now for this reason." I think that that's just from me spending time in there and enjoying to people-watch.
	2.2	Collaborating/ Communicating – Working with others	Discussion of the two or more people who do not fully understand but are working towards understanding or achieving a goal, whether through brainstorming, thinking of new concepts and ideas together, talking to understand together, and working together.	Code when participants point to the importance of relationship, communication, and collaboration with others within makerspaces as important. This is a mutual activity of "talking with others" or other synonyms for talk may be used, such as "working it through with others."	And I think it's a lot of the way that people learn in the machine shop, from what I've seen or like encountered, is just talking to people.	And then we did that, and we're like, "Okay, that targets different muscles, but you can't always have it have -- like how do we have enough beads that will roll and stuff like that. So it was like moving through just like crazy ideas of this could work, trying it and being like, "Okay, what did we learn from this idea? We learned that this part and this part worked, and that was good" Whereas, these parts failed, and that's why we're not going with this design. We need a new concept that embodies the good, but not the bad that we've learned from this idea, if that makes sense?
	2.3	Receiving help or training/ Communicating – Receiving or soliciting help	Discussion of receiving help in order to learn a tool or figure out what to do. In this process, a person with knowledge (or understanding) giving assistance to a person without the knowledge so as to help them understand conceptually; training can also be seen as when a person uses tutorials or training manuals in order to figure out how to do something.	Code when participant discusses situations when they asked a person with more knowledge for assistance or training. This code occurs most often when someone has authority in the space, such as a student worker. The distinction between 2.2 and this code is that 2.2 is "working together to understand" and this code has an authority or superior comprehension that assists another, gives advice, communicates experience, offers an opinion based on experience, or provides uninvested guidance.	I can be like, "Hey, I want to try this. Tell me if it's stupid, or if there's a different way I should do this." And they'll be like, "Yeah, you could totally do this. Like let me help you."	But sometimes I just like genuinely interested in what people are doing. And they're like, "Oh, this is cool. I'm trying to do this, but I'm frustrated because I can't figure out how this works." And I'm like, "Hey, do you know about this? Maybe you can try this and see if it works." And learning from like someone that just knows knowledge that you don't know, and putting it together to help you make something -- to help you make something better than what it was before, because you could be frustrated, not knowing how to do something. And be like, "Hey, you can totally make that on the lathe in like five minutes."
	2.4	Giving help/ Communicating – Giving help or instruction	Discussion on training, teaching, or providing direct instruction for someone in order to help them with a task or to make them proficient on some equipment.	Code when participant helps another person or group. The participant is more knowledgeable or is an authority in the space; the participant is able to construct solutions and viable options for other persons to pursue in order to accomplish a task.	Like one group wanted to mold something. And I had usually done rubber molds so then I through helping to make sure that they didn't like kill themselves from how to use like rubber molds, as well. So through that I gained like more experience on like the drill press and the CNC mill.	So, like, I'm -- this is, like, two or three different ways I would approach this. I think this might be the best for what you're doing. We could try that. If this doesn't work, let's try this instead. And then I kind of walk them through it if think want to be walked through or not.
	2.5	Leading/ Managing - Administering	Discussion on caring for or taking on responsibilities in the community along with recognizing social nuances to help with leading in the space.	Code when participant has a leadership role and has backend responsibilities. This comes into play when a participant talks about being on an executive board or being a mentor. These help to indicate that the participant will have more managing and leading opportunities in their narrative.	I am the Director of Programming so I do like workshops and events and stuff. So I plan workshops. I plan like our internal social events. I plan our banquet at the end of the year.	But like as a [student worker], when I'm like on-shift, I'm always -- when I'm like on the shift as a [student worker], like my main goal is to keep people safe, right, whether I'm in the wood room and like watching people, making sure nobody drills through their hands, making sure everybody's got their hair tied back and has got like safety glasses on, and everything, and just kind of observing, but also it's really easy to tell when someone walks in the space and they have this particular expression.

Table 3 Continued.

Product of Learning: Cognitive	**3**	**CONTENT KNOWLEDGE AND SKILLS**	Discussion on the knowledge, skills, and technical jargon acquired in various subject-areas.	Code when participant describes the topics associated with different subject areas. Typically, this higher level code covers areas not addressed below, such as when a student talks about learning concepts of thermodynamics or statics better from the makerspace. This code does not look at depth of their understanding, but is associated with developing and acquiring more knowledge. *This code can be by itself or paired with the codes below.*	Of like when you have a problem that you don't know what you're doing, applying things that you learned in other classes or things that you already know and utilizing them to solve whatever you need to solve.	I still understand truss, even though that was a class I should not have passed, I was that bad at it, but I still understand that entire concept, because I actually went from like, ground, to like making it and seeing how it works, how it bends, and like, what--if I change this and that, this stops bending, and things like that. Textbook is great, but like, I learn better by actually doing it.
	3.1	Design	Discussion on the formal conceptual, ideation, problem-solving, or prototyping processes/techniques that are used to create a design or to perform a task.	Code when participant uses words like "problem-solving," "brainstorming," "prototyping," "design." This code encompasses both the overarching design process and the specific techniques used throughout the process in order to create a final design. Some techniques that are not as well-known might include branding or interviewing. This code is different than ingenuity (5) in that design is more of a formal process; however, this code can be paired with any in ingenuity (5).	And they wanted texture to be inspired by your brand, but these lines didn't make as much as sense for a curved object or for putting the kind of technology in it that I needed to and the way it was going to be interacted with and having these indents, that had technology embedded in them made much more sense. And it just made a smoother process.	Yeah, because when I'm designing something or when I'm trying to fix something that's broken it's like I know that these are the probable reasons why this device or whatever I'm trying to do is like breaking or not working and being like, okay, well, I know about these two and these two probably aren't the solution to this problem.
	3.2	Manufacturing and Tools	Discussion on the physical tools, machines, devices, or apparatuses that perform a task.	Code when participant points the tools or machines that they use or have learned about. This code is to capture the participant's knowledge about the physical tools and machines. Machines such as the "3D printer," "laser cutter," "vinyl cutter," "hammer," "chisel," "bandsaw," etc. This code can be applied if the participant says that they know how to use the machine.	Like, for example, laser cutter, if you don't turn on that fan, like, one, it will likely ruin your project, because there's like a lot of dust and debris in there, and then two, it'll make the whole lab smoke up and stink, which is like not supposed to happen.	The nice thing about 3D printing is like the lathe you spend hours knowing how to use it and then you do trial and error to figure out what's the best way to do what you want to do, right? And like the 3D printers, anyone can make something or pull them off from online and print it, so that's a lot different. And so then we ended up going to that because you could have all your group working on the same thing, so that ended up working a lot better.
	3.3	Computational Tools	Discussion on computer-based software that are used to perform a task.	Code when participant uses computer software, such as "Inkscape," "Solidworks," "Fusion," "Sketchup," or "Matlab." This code could be seen with 5.2 and 5.4 when the participant describes a project that they are making. Similar to 3.2, the code can be applied if the participant makes mention towards knowing how to use the software.	And, then once we had our design, we had to CAD it in Solidworks, Inventure, anything you want. I ended up using Solidworks…	And then or I'd be like, oh, I'll try to laser cut this, I don't know how to use illustrator, can you show me how to do it? That type of thing. And then like learning how to do it or like Googling what I needed to in illustrator. I was making like little gifts and stuff, yeah.
	3.4	Materials	Discussion on the materials that are used in order to carry out a task, such as understanding of the material's properties.	Code when participant reveals their knowledge about the material choices and properties, like when they give reasons to use one material over another, just say "this material is flexible," or describe the filament properties of a 3D printer.	Sewing is a little different since your material is so flexible; you have to kind of be aware of how the material is going to all come together.	So now we might try that, because our first thought was, oh, let's grind up this glass really, really fine, makes it look like an epoxy and then use that as like a top coat to wood, right? So then you would have like your balsa wood or whatever, a light wood you'd want to use or bamboo, that's like a flexible wood, and then you would just top that and seal it. Yeah, so it's just like different ways of kind of doing the same thing.

Table 3 Continued.

Product of Learning: Cognitive	**4**	**CULTURAL KNOWLEDGE AND SKILLS**	Discussion on navigating a community [in this case the makerspace community] along with the physical space and what the person comes to understand about that community.	Code when participant reports on the community and what they know about the way the community functions and what it is like to be in the makerspace. *This code can be by itself or paired with the codes below. All the codes below can easily be found together.*	I think I would talk about mainly the privacy aspect of it. Because it's -- like honestly, like I cannot highlight enough that that's my favorite like, one, the fact that you can go like anytime once you're like trained.	So I think it was more the atmosphere that pushed me towards BME because if I'm at BME I know basically everyone that's there. And then if you know someone it's easier to be like, hey, what are you doing versus like a total stranger wanting to know what you're doing. It's kind of like there's a different barrier, I guess.
	4.1	Access conventions and protocols	Discussion on the ability to access the different aspects to a community and the community's resources.	Code when participant describes what is available for them to use, what they may or may not have access to, and what the potential procedures are to gain access. Or, if the participant doesn't know what is accessible and available, this is equally important to code.	...because I don't have access to this lab for the purpose of a class or a research. It's just me using it as like a personal benefit, I guess. Because like I would not have known this existed if it weren't for like my friends	And then my third year, that was last year, yeah, my third year Fall, I -- which was last Fall -- I was in the design course 2310. That's the course that Wilson and Daniel are in charge of. And so through that design we got more exposure to the machine shop that you were in.
	4.2	Roles and structure of participation	Discussion on the roles and responsibilities of the people involved in the community.	Code when participant talks about who the people are in the space, what their roles are, how being involved in the space works. This can be presented in the straightforward form of "there are users, student mentors, and faculty advisors or in a more implicit form where the responsibilities of a person or the relationship of the people in the community are highlighted.	We have our [student worker] schedule, like our names. And if you come to the shop, you're like, "Hey, are you the [student worker]?" And you're like yes or no. Yeah, and like "Oh." Like when I see someone and they look confused, I'm like, "Hey, I'm Rebecca, the [student worker]. Like do you need help on something?" And if people are confused, they usually like yes please help me. Or they'll be like no, I'm looking for Wilson, because most people will look for Wilson, and then Wilson will come in there, he'll be like, "Go find Rebecca, because I'm too busy to deal with you."	So like the people that are [student worker] are people with like good energy, a passion to make things, know how to use a few of the machines, and are like receptive to help people, because like we're -- as a [student worker], like I'm not like the god to be like, "You shouldn't be doing that," unless it's like a safety issue. But like if someone's doing something in a stupid way, I'm not going to say something unless they ask me about it.
	4.3	Rules of the community	Discussion on the way the community works, the rules (both implicit and explicit) that are in place or have changed - includes rules on safety and how safety is handled.	Code when participant says things like "you can do this" or "you are not allowed to do this." Safety rules are a large component to this code.	They just kind of -- like the big -- one of our big rules is don't ever sell anything you make in the studio. We get our money from the government. If you sell things, it's technically misuse of government funds, and whatever you made, and whatever money you made is not going to be worth the massive fine that the government puts on you for doing that. Just do not.	
	4.4	Gendered experiences	Discussion on the way that gender is perceived in the community or experiences seemingly associated with gender.	Code when participant stresses social experiences or nuances that have a link with gender rules. Things like "It's probably because I'm a woman," "the boys would snicker at me," or "I'm empowered because I'm a woman." If the participant says "I'm not sure if it's because I am woman" then it still should be coded here.	I think it's always fun to see, like, the look of surprise if, like, a guy that I haven't seen before comes in the shop to, like, do something and they see me, like, working. They kind of, like, give me a weird look, like, "Do you know what you're doing?"	And that's always weird because they're like, "You're a girl. Like, you should like engineering. You should -- you should do home ec or something." Like, you know, like, the whole -- I think it's changing now. But, like, there's still the whole, like, traditionally women go to college to be wives, not to, like, learn things to accelerate their own career and ambition, right.

Table 3 Continued.

Product of Learning: Intrapersonal	**5**	**INGENUITY**	Discussion on an informal seeking out solutions or being aware of strategies to use in performing a task.	Code when participant shares a strategic, efficient, or clever approach to accomplishing a task. The words "creative," "innovative, " "strategy," and "efficiency" help to pinpoint areas where this code applies. Code is meant to capture when a participant thinks outside of the box or has this sense of what to do. This code is different than 3.1 in that design is a formal process; however, ingenuity can be found during the design process. *This code can be by itself or paired with the codes below. All the codes below can easily be found together.*	The thing with the topic of health is so big that it was so much easier to pick one thing-- like, the faster you can narrow down what you were doing, the more energy you could focus on what your final project was going to be.	Because we as students are fueled by a need to answer questions, I think. And that's interesting in the fact that we're always creating solutions.
	5.1	Improvisation	Discussion on figuring out how to accomplish a task without previous preparation or knowledge.	Code when participant talks about not knowing what to do and coming up with a solution, even if it is out of left field. Might be accompanied by "let's just try this." This code can be seen when an error occurs and the person has to think quickly on their feet OR can be seen when a person has decided that they want to make something and they figure out what to make on the spot.	So I went to like Home Depot or Lowes, and I got like a two-by-four piece of plywood. I sanded it, made it look nice, and then took little hangers that people use for -- for like keys, small ones, and I just put a bunch of them at spaces and intervals that I liked, and then -- we're not allowed to have hooks in our walls at Tech, so I got like enough Command strips to hold the weight of the board plus all of my hats, and then I just like taped the -- put the Command hooks on, and I strung like fishing line to it to stick it on there. And so now I have a hat rack in my room for no reason besides the fact that I was annoyed at having to unstack my hats every day.	Extrapolating what I've learned from, like, design and taking it to researching, and you're like, "Oh, I see this problem. Let me figure out how to make something to fix this problem because my experiments aren't running correctly."
	5.2	Opportunism	Discussion on being cognizant, aware of, or open to other ideas within one's surroundings and what could be used for a project, or vice versa.	Code when participant sees how what they learn or see in the makerspace can be used in other scenarios, or vice versa. For example, when a participant sees something and goes "I could use that for my own project" then that is an instance of when this code should be applied.	So I was at a friend's like looking at their coat hanger, and I was like, why don't I just do that with my hats?	
	5.3	Resourcefulness	Discussion on using available resources and finding strategic ways to achieve a goal or complete a task.	Code when participant talks about using what they have to make something, talking to someone else more knowledgeable, or Googling something. Examples might be like "what do I have that I can already use" or "I used acrylic because that's what I had."	Let me think what I can do with what I have.	But, yeah, it's just like I don't know, I feel like there's no way of like, oh, the first thing I do is 3D print it and then I'll laser cut and then I learn how to use the laser and then the bandsaw, and now I'm going to learn how to use the CNC mill or there's no like steps to go through, it's more of just the way I've done it it's just I'm making something and how do I do it and utilize resources that we already have?

Table 3 Continued.

Product of Learning: Intrapersonal	**6**	**SELF AWARENESS**	Discussion on the motivating factors towards one's attitude along with one's personal attributes/characteristics.	Code when participant conveys an intrapersonal understanding as they describe a scenario that showcases their growth, attitude, motivation, and character. This can be as simple as their likes and dislikes. *This code can be by itself or paired with the codes below.*	But I'm like, I'd rather like spend 50 hours on the lathe and create something like super-awesome to me versus just printing something	Or hearing bandsawing -- I like the smell of wood, because it's like the smell of creating something
	6.1	Confidence	Discussion on developing confidence, acquiring comfort, and overcoming fear.	Code when participant demonstrates how they are confident, proud, validated, comfortable, or unafraid in either using the machines, talking to other people in the space, etc. The code is meant to capture this change in one's perspective of themselves and their ability to do something.	So I think, like, I feel more comfortable going up to anyone in the makerspace and being like, "Yo, what are you doing?" And, like, that's probably not a conversation I would start with, like, anyone out in the street, you know? But I'm more comfortable in that space to do so.	And, then the third time, I was much more confident and able to do the things I needed to do on the waterjet and I'm much safer helping people do things on the waterjet now.
	6.2	Patience	Discussion on the value of time, taking the time to perform a task and allowing oneself to be engrossed by working on a project.	Code when participant emphasizes time, focus, and patience. Participant talks about the time it takes to do things. When talking about this, they may say "it just takes time and that's okay" which indicates their ability to be patient. Also connected is the ability for students to get in a zone, where they are willing to focus on the task in front of them and allow time to pass without worry.	Me time, downtime where I'm, like, thinking about stuff and creating things, but, like, everything else I can put on the back burner for, like, an hour and a half while I go and just make something in the shop. And, like, that's been kind of, like, therapeutic. It's, like, nice to just do something. And I think that's what pushed me to continue doing it.	But it takes like time, and you investing time and labor to create something awesome on the mill, so. But I also spend hours there, so I can -- I'm able to appreciate spending hours to create something cool. But yeah.
	6.3	Resilience	Discussion on messing up or struggling but continuing to keep going with a task.	Code when participant talks about failing or struggling through a problem but does not give up; they keep pushing to figure out what is wrong or how to solve the problem at hand. This is the person's ability to bounce back from obstacles or challenges. This code can accompany 1.2 and 1.1.	So, you're encouraged to - if you're doing something wrong, we will fail you, teach you what you did wrong, teach you how to take the test again, and then you can come back and retake it until you have those skills. So, like I failed my waterjet test three times, because I just - I was nervous and I didn't know how to do it. And, then the third time, I was much more confident and able to do the things I needed to do on the waterjet and I'm much safer helping people do things on the waterjet now.	That's how usually I learn. I'm like, oh, that's cool, let me see if I can do that and then I try it. And then I'm like, okay, I can't do it this way, but then I figure out a way around it to do what I want it to do, if that makes sense?
	6.4	Reflective	Discussion on sharing one's perspective about what they've learned about themselves or the community.	Code when participant highlights what they like and don't like, their perspective on making, makerspaces, and their own role in the community. This code captures how the participant perceives the impact of the makerspace and the meaning in their life. Along with how they see others in relation to the makerspace; the word "realize" or phrase "I don't think people realize" is usually a good indicator. *It is important to note that the interviewing process is reflective by nature; therefore, this code encompasses a thought-evoking mindset.*	And like I wouldn't have hung out as much in the shop if I didn't have 2310.	So I think most BME's first exposure to the BME shop ends up being 2310 because they're forced to prototype something. And I think that the earlier you take that class the more it jumpstarts you if you enjoy it, to go to the shop and do stuff.

4.3.1 Modes of Learning

The learning modalities fall into two primary categories: learning by doing and learning through others. The difference between modes lies in the fact the learning by doing is a physical activity, and learning through others is a social activity.

Learning by doing is characterized by the discussion of learning through experiences or needing to learn by working with one's hands. Five secondary categories support the 'learning by doing' primary category: failing, struggling, practicing, iterating, and exploring. While all of these categories are tightly linked and may appear together in the data, the typology articulates the distinctions between each category. While failing and struggling involve contention in the learning process, failing refers to when mistakes are made or one falls short of succeeding in a task, whereas struggling focuses on the instances when a participant endures frustrations or challenges when trying to complete a task. Further, the other three categories involve an experimentation process. However, practicing involves when a participant seeks to gain proficiency in a task, iterating corresponds to intentional experimenting towards making a design right, and then exploring focuses on the experimenting process associated with figuring out a solution. These distinctions are made in order to showcase the unique differences in how a participant learns by doing.

Learning through others refers to the instances when a participant discusses learning from other individuals, whether from just watching or by interacting with them. There are five secondary categories associated with learning through others: observing, collaborating, receiving help or training, giving help, and leading. Throughout the development of the typology, it became clear that being a participant is involved in a variety of interactions which can change depending on the participant's role in the space. While at first glance the categories seem to have clear distinctions by their labels, there are some important characterizations to take into consideration. First, observing can sometimes be intentional and associated with the training process, as a participant watches how to do an activity in order to gain experience. Alternatively, observing can emerge from the participant sitting in the space and seeing what other people are doing.

Moreover, collaborating is associated with two or more people working together to figure out how to achieve a task. In the makerspace setting, the collaboration process can quickly evolve into a helping process or vice versa. Here the distinction lies in the fact that collaborating is occurring when two people are both not fully understanding and work to develop an understanding, whereas helping is when one person is in the role of a helper (having supposedly more knowledge than another). Later, it became clear that receiving help and giving help were two distinct entities. The process and humility in asking for help permitted a different understanding and gaining of knowledge than the act of giving help. One participant supports this notion by saying, "The best way that I can learn all this stuff is by teaching it." As a final category for learning through others, leading caters to the acquiring of knowledge through having more managerial responsibilities facilitated by one's involvement in the space. For example, when a participant becomes a student worker or even a member of the executive board, they have to engage in leadership skills so as to ensure that they abide by their given responsibilities.

4.3.2 Products of Learning

4.3.2.1 The Cognitive Competencies

Content knowledge and cultural knowledge are the two primary categories for cognitive competencies. Content knowledge and skills pertain to when the participant gains an understanding or skills associated with various subject-areas. In the narratives, the women students talked primarily of four main categories: design, manufacturing and tools, computational tools, and materials. In the 'design category,' participants discuss the formal processes involved in creating a design or performing a task. This includes, but is not limited to, problem identification, ideation, and prototyping. The techniques that a participant may use in the design process, such as interviewing the population for design insights or branding the design, are also included in the design category. Often seen with design are the participant's manufacturing and tool knowledge. This refers to the physical tools, machines, devices, and apparatuses that a participant learns how to use, when to use, or how it works. Unfortunately, this category does not capture the depth of a person's knowledge of tools and manufacturing. As such, a participant knowing how to 3D print is categorized the same as a participant knowing how to fix an advanced 3D printer. The research team discussed ways in which to further evaluate for a depth of knowledge, but made decisions to table analysis for the depth of knowledge for future work and focused on simply capturing the breadth of knowledge. Coupled well with the aforementioned content knowledge categories are the final two categories of computational tools and materials. Computational tools are a participant's knowledge of computer-based software, and the 'materials' category is their understanding of material properties and what certain materials are appropriate for a design. While the ‘content knowledge and skills’ categories are distinct from one another, they often appear together in the data.

The ‘cultural knowledge and skills’ category organizes the data that talks about navigating the makerspace community, whether that be through access conventions and protocols, roles and structure of participation, rules of the community, or gendered experiences. Through cultural knowledge and skills, the participant comes to understand the nuances and rules of the community. Participants discuss experiences on how they gained access to the makerspace, their perceptions of accessibility before and after involvement, and what they know to be available for them to use. This type of learning is critical in showcasing how university makerspaces are succeeding or failing at providing access to students. Access is a highly interpretive entity, and it is the responsibility of the makerspace community to decrease barriers to entry and provide clarity on access for both insiders and outsiders. Furthermore, cultural knowledge and skills include both roles and rules of the community. The participants learn the hierarchical structure of the makerspace community, the responsibilities of the different members, and their own personal role in the community. Leveraging their understanding of the different roles, the participants also come to know the rules for working and interacting with the social community and the materials in the community. Rules include more explicitly defined processes, such as safety procedures, or more implicitly known process, such as it being okay to fail. Lastly, the ‘gendered experiences’ category aims to capture the women’s interactions that they relate to how gender is perceived in the community. Seeing that this work focuses on women’s experiences, it became evident during the data analysis process that the typology also needed to allow for the emergence and acquisition of the gendered experiences within the community. This would allow for a more in-depth understanding of the women's narratives and how that impacts their learning in the makerspace. In essence, this 'cultural knowledge and skills' category is relatable to any type of community or culture.

4.3.2.2 The Interpersonal Competencies

Through the analysis process, we realized that the interpersonal competencies aligned with the 'learning through others' categories. The two primary 'interpersonal' categories are communicating and managing. The majority of the categories under learning through others focus on the practice and acquisition of communication skills, where the final category (leading) focuses on the management skills acquired. In the typology, the 'learning through others' and the 'communicating/managing' categories are not separated. After undergoing the efforts to obtain inter-rater reliability, the interviewer and the other researcher recognized the mapping of the categories. To reconcile the fact that the data would be coded twice, the typology was updated to have the learning through others categories with the communicating and managing categories. Therefore, the observing modality would also be coded as listening, collaborating as working with others, receiving help as receiving or soliciting help, giving help as giving help or instruction, and leading as administering. In turn, the combining of categories alleviated the cognitive load, confusion, and double categorization of the typology.

4.3.2.3 The Intrapersonal Competencies

Finally, the intrapersonal competencies facilitate the discussion on internally acquired skills associated with ingenuity and the competence relating to self-awareness. Ingenuity aims to capture the instances when a participant informally uses innovative means or strategies to pursue a solution. Ingenuity resolves itself into improvisation, opportunism, and resourcefulness. In general, a participant's narrative will engage more than one of these secondary categories in a given account. For improvisation, a participant works to figure out how to accomplish a task despite a lack of previous preparation or knowledge. This can be quite common when a participant has a project that falls apart the night before it was due, and they have to figure out a quick solution. When figuring out a quick solution, the participant may even pull a strategy from the 'opportunism' category. Opportunism, described in the entrepreneurship literature (Lau et al., 2012), refers to when a participant recognizes and exploits opportunities to the ways in which other solutions in their surroundings may be applicable to a design task. This can also take shape where a participant begins to be aware of design in the world around them and perhaps build a collection of designs that they see as transferrable to other design tasks. This category may be seen as a means for acquiring inspiration in design. In the third category of resourcefulness, the participant strategically uses available resources as a way to achieve a goal or complete a task. Participants may find that they want to make something in the shop, so they look to what machines, tools, and materials are available for them to use. These types of categories characterized under ingenuity are linked to the participant's ability to adapt to given situations.

Also, an intrapersonal competency is the 'self-awareness' category, which reflects the motivating factors towards one's attitude and personal characteristics. While this category could easily have an abundance of secondary categories, we highlight four main underlying areas that emerge in the data: confidence, patience, resilience, and reflective. To reiterate, we recognize that there is an abundance of categories that could characterize the nuances in the data; however, we focus on four that are able to capture instances of self-awareness that permeate the data. As a participant learns in the makerspace, they become more confident and comfortable while also overcoming the fears or facing their anxieties associated with the makerspace. This may be in relation to simply entering the space or may be with using the machines. Both types of confidence instances are included in this category. For the next category, patience includes the participant taking the time to perform a task or allowing themselves to be engrossed in the task. Few participants articulate acquiring patience, but there are numerous instances of them discussing the patient endeavors for creating a design or achieving a goal. Of a similar vein is the 'resilience' category. In this category, participants do not refer to gaining resilience, but rather they talk about instances where they fight through a task or bounce back from failure. Evidently, resilience is closely related to the 'failing' and 'struggling' categories within the 'learning by doing' category. Also, it is necessary to address that the 'patience' and 'resilience' categories have an overlap when it comes to perseverance. While perseverance is not granted its' own label, the instances where perseverance is evident must be carefully identified as patience, resilience, or both. Then, holding the position of the last category in the typology is the reflective category. While the very nature of the interviews is reflective, the 'reflective' category aims to capture when the participant shares their perspective about what they are learning about themselves or the community. This is highlighted when the participants realize that their involvement in the makerspace has changed their lives or when the participants see how important it is to have a "toolbox of design." This category demonstrates that participants are acquiring skills in reflection from being involved in the makerspace, which given the work on the need for reflection in engineering design

(Csavina et al., 2016; Turns et al., 2015) showcases a means for students to become reflective that is neither imposed nor forced.

4.3.3 The Breadth of Learning

Through developing out a thorough typology, we have been able to show the breadth of learning that women are experiencing in university makerspaces. As evidenced, this learning is more than just manufacturing and tool knowledge. Women students are engaging both content and culture knowledge and skills, along with communication, management, ingenuity, and self-awareness. With this expansive typology, we are then able to extract the main claims for learning that emerge from the data as a means to craft a model for how the types of learning develop and interact (answering the second research question).

4.4 Findings on Learning in Makerspaces

After obtaining inter-rater reliability on the primary categories, the interviewer coded all of the data using the full typology, which at this point included the second round of interview data. The fully coded data is represented in the tree map (see Figure 12 for detailed tree map), which represents the dimensions of the categories through nested rectangles. The tree map sets the foundation for the learning model by showcasing the magnitude of learning associated with each learning category. As evidenced, content and cultural knowledge are shown as having equal magnitude, followed by self-awareness, communicating/learning through others, then ingenuity and learning by failing with equal magnitude, and lastly, managing/learning through others. The equal magnitude of content and cultural knowledge implies a give and take between the two cognitive competencies –

that they are equally engaged during the learning process. For example, as a woman gains access to the makerspace then the more opportunities to gain competence in the tools, or as a woman wants to build a design then the more she has to learn about who to talk to and what is and is not allowed in the space. Also emerging from the tree map is the difference in magnitude of the intrapersonal competencies. The tree map shows that self-awareness is much larger than that of ingenuity. This resonates with the notion that a woman would need to gain patience, resilience, and confidence towards their ability to think on the spot or outside of the box. Additionally, the tree map demonstrates that communicating is also much larger in comparison to managing, where communicating is a foundation for managing skills. This is to be expected since managing strategies are associated with taking on leadership roles, most specifically for roles on the community's executive board. The emerging patterns of the tree map help to articulate the ways in which women's design and learning pathways are developing. In the next step, we examine the themes that emerge from the data (Figure 13) and how these themes help to build out the learning and design model, Figure 14.

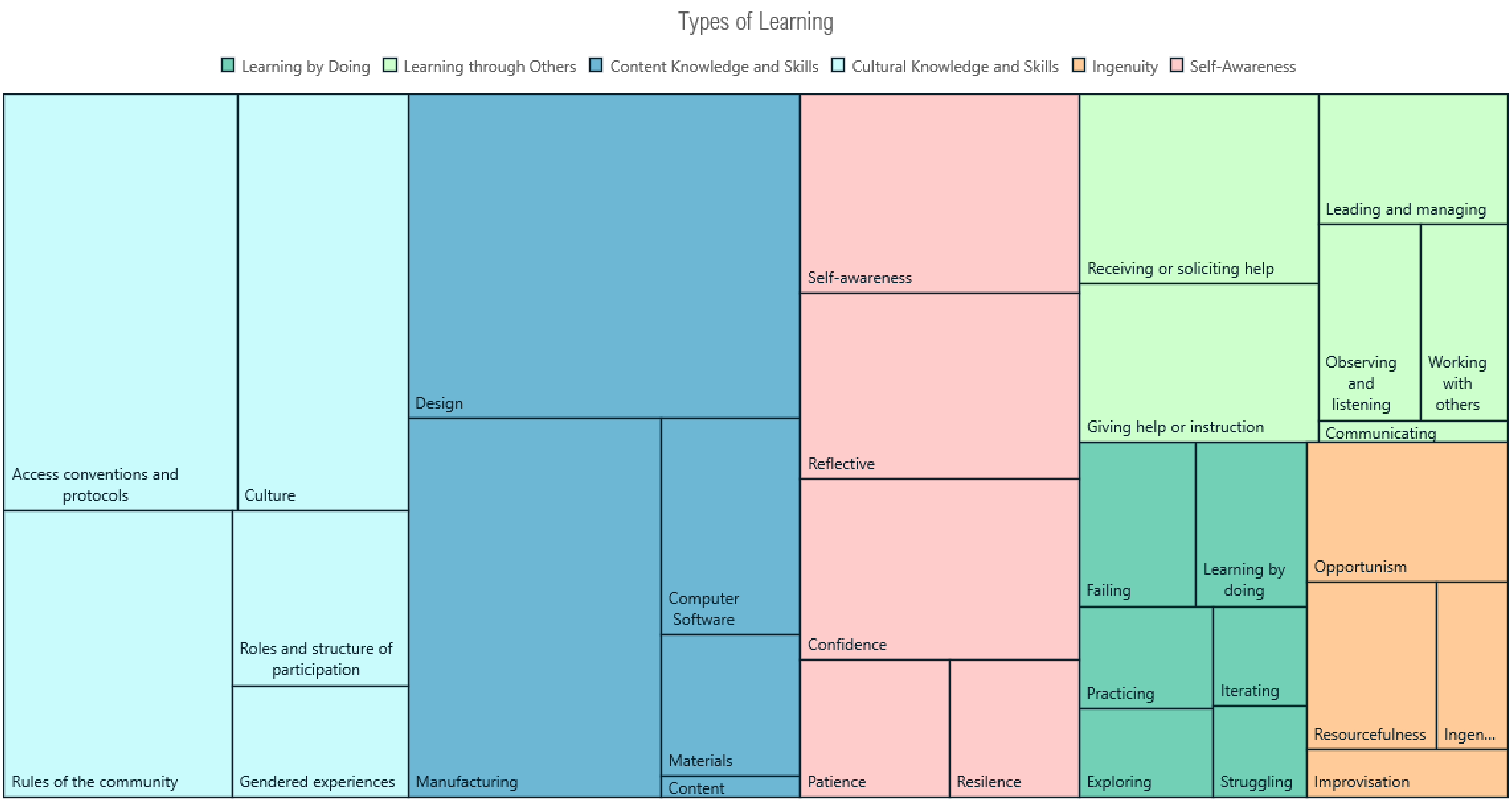

Figure 12: Tree map of the types of learning in makerspaces.

Figure 13: Themes of learning that emerge from the data.

4.4.1 Makerspaces as an "environment of everybody is learning"

"Everyone's learning all the time."

Makerspaces support the women students through instilling the notion that "everyone's learning all the time," which is encouraged by an environment that *invites failure* and *supports asking for help*. These elements allow for a culture that allows students to create freely in a judgment-free environment, where "people don't judge when I make mistakes." "The culture there is very everyone's there to learn something new, and no one knows how to use everything in the space." The makerspace changes the dynamic of learning for women students. Naturally, the women students do not want to fail; this is heavily portrayed in the following woman's narrative:

> When I do things, I do them right or I just don't. I mean, like, with tools that I am proficient in, I'm going to take more risks and be -- but, if I don't feel proficient in something -- I mean, it also helps that I can go to someone and be like, "Hey can you help me out with this?" But, like, sometimes it will be like, I don't want to do

> this project, because I don't think I'm good enough at it and I really don't want to fail at it.

In this short excerpt, it is clear the tension that comes from not wanting fail and then seeing oneself as not good enough, even with the opportunity to ask for help. She struggles to resolve the conflict of proficiency and failure. This conflict is heavily rooted in the classroom, where one's proficiency is based on letter grades and assessed on one's ability to succeed in homework, exams, quizzes, and projects. With this attitude, students enter into the spaces with intrapersonal barriers that result in creating design barriers.

> You've always been taught that like when you do something wrong it's because you're like dumb or you're like -- you haven't learned something correctly is why you failed. I think a lot of [university] kids link that together, so they're like afraid of failure, so when their design fails, when their 3D print fails, they think it's something they've done versus like, oh -- it's not something -- yeah, it's something you've done because you've designed things wrong, but how do you learn from that to make it right versus just accepting that you've failed and maybe could try something else, if that makes sense.

Students inherently extrapolate failure in an activity to them being a failure. This form of extrapolation is present in Brown's (2017) work on vulnerability, shame, and empathy where people extrapolate a situation and create a lie that they tell themselves, which for the learning in makerspaces might read something like "the lie that I am telling myself is because I failed then I am a failure." Overcoming the thoughts that "It's too hard; I can't; I can't understand it; I'm not smart enough" can be challenging. However, "not being afraid to start is a big thing," and the makerspace provides the opportunity to overcome the fears of failure and concern that one is not good enough. The makerspace "gave me confidence that I could create on my own. I feel like the makerspace still endorsed that better than the class did" because "at the space you actually make something and get a physical product. In class, you're just doing it for a grade, which is a lot less fun than doing it for yourself." The act of creating and generating tangible products through failing, struggling, practicing, iterating, and exploring enables the women students to embrace failure and grow in confidence in an atmosphere that encourages learning.

"And if all those fail, I can find someone who knows more who can take their steps." Of a similar vein, the makerspace environment not only encourages learning and failure but the act of asking for help. Similar to not feeling good enough, asking for help has a connotation of weakness, where one who asks for help is not strong enough to do something on their own or is not knowledgeable. Asking for help requires the women students to recognize that they are learners and that asking for help is not a weakness. However, asking questions comes with uncertainty in how one will respond, especially in an environment that women tend to avoid makerspaces because they are typically dominated by men (Faulkner & McClard, 2014). For instance, one participant had helped to change the culture of the space, but when she had started out using the makerspace, the response towards her questions was not well received:

> And so, I had to ask a lot of questions, to people that were pretty condescending, and pretty mean, just for no reason … I didn't want to ask people all that information one at a time. I wanted to space it out, so I could space out the feeling of condescension and embarrassment … So what I did was, I avoided the people who

> were [jerks] to me, and I went to other people who seemed knowledgeable. Sometimes, they turned out to be not knowledgeable.

From here, this participant made efforts to change the culture of the makerspace to where all members recognize the value of asking questions and of learning. With a focus on this type of learning, other women students became “not afraid to ask questions anymore” because of the makerspace’s welcoming environment. A learning that fosters seeking help allows women students to: 1) “realize what went wrong, and making sure that the situation didn't happen again for any of the users,” 2) be “able to say, ‘I don't know, let me get back to you,’ has been a really important thing for me to develop and a lot of that's come from working in the shop,” and 3) to learn that “if you want to learn how to make stuff at [the Makerspace] you're going to have to ask people for help, or just talk to people.” The makerspace breaks down the barrier that students have to know everything, which can be especially challenging for women who are student workers in the space. While they recognize that “there's a lot to gain from being in a position to teach others and also say, I don't know,” they “want to have the answer for people all the time” which instills in them a desire to learn and ask questions so that they can have the right answers for people the next time. “The beauty of the [Makerspace] is that there's always going to be someone who knows and always going to be someone who has a specialty is some realm or whatever.” One participant describes the open learning of the space and how she overcomes the worry in failing:

> It's because everyone's so open in just sharing their knowledge in the maker space. Anytime I want to know a little bit more about something, I ask. It's the word of mouth that helps in that. Then if I'm a little skeptical on how to operate a tool, I just

do it because what's the worst that can happen if I know how to do it but it's just maybe a little worried or something like that. I just go for it.

By no means is this participant suggesting that a person with zero knowledge on a tool should try without asking. Here, she describes that she will ask for help as necessary, but sometimes it's her own skepticism and worry as a barrier to her just trying to operate a tool. The tension between failure and proficiency is reconciled in the culture of a makerspace that allows learning all the time.

Another aspect of a learning-infused culture is that learning permeates the essence of the makerspace and *engages learning and inspiration* from working on projects, interacting with others, or seeing what other people are doing. Simply by being in the space, women students are "getting to see the tangible results of all these great ideas people have" which is "really inspiring to see all these projects that people come in with." Seeing what other people are doing coupled with being encouraged to ask questions allows "a lot of it is just kind of learning by either watching other people or learning by asking them questions about like, 'Hey, I saw you were doing this. It looked really cool. Could you tell me a little bit more about what you're doing?'" Learning from asking questions and seeing what other people are doing then opens the opportunity for pondering "like, 'Oh, how can I apply your knowledge to what I'm doing?' I think it's a lot of what I've seen and experienced myself with like how people learn in that environment, which is pretty cool."

Alternatively, there are numerous ways in which learning is engaged, which is highly reflected in the numerous categories for learning modalities in the typology. Table 4 presents a few instances where participants have expressed how they learn and showcases how learning comes “by teaching,” “in passing,” by “word of mouth and practice,” by “doing things,” by “actually making something,” by “watching other people,” and by “asking them questions.” The extensive means through which women students acquire knowledge is a direct result of the culture and environment of the makerspace.

A unique tension shown in Table 4 is the learning how to use machines is by manuals, where the next participant states that “you can study a manual … all you want,” but taking a 3D printer apart and putting it back together brings forth the best way to learn about the machine. While these may seem in conflict with one another, these excerpts are not provided in the full context of the participant’s narratives. The woman who talks about reading manuals as a form of learning is referring to the fact that a manual sets the foundation for where to start in truly understanding the machine thoroughly. This same participant characterizes herself as a hands-on learner and later mentions that “we don't realize how intricate computers are until we actually open one, and be like, what's wrong with you?”; her discussion on learning through manuals stems from her involvement in helping to set up one of the makerspaces on campus. In the process of setting up the makerspace, the team decided to make certain members ‘experts’ on specified equipment, and these ‘experts’ were to read the manuals so as to be able to fix the machine and ensure safe use of the machine. The follow-up excerpt is in the context of recognizing that written instructions can only go so far and sometimes a situation occurs that a manual cannot resolve, but rather an individual must figure out a solution by working with their hands and problem-solving. “This is something I've learned through like [messing] up, which is like when you're in design -- or in anything, anything you learn, like 3D printing, any of the tools, the 3D print, the CNC mill, the bandsaw, all of those are tools in your toolbox of design." Ultimately, the different ways of learning, whether that be with the manual or through watching others, contribute to this "toolbox of design" because this allows for opportunities "if you just have the ideas, then they're in your toolbox, stored away to where you can use them later. Yeah, it's cool. So I think the [makerspace] is what we make it to be."

Table 4: Examples of the ways in which women students are learning.

The best way that I can learn all this stuff is by teaching it.
A lot of learning from other [student worker's] in passing.
Honestly, mostly word of mouth and practice, word of mouth and doing things.
I learn a little bit when I watch someone else do it. When I actually make something and think about the process behind making it, it is the craziest experience. You're learning so much more than you would by just watching someone do it. It's just like anything else.
I'm much better at active learning; I have to be doing things. I can't just be -- I can't just watch things happen. And, being able to do things is really the best way to learn.
A lot of it is just kind of learning by either watching other people, or learning by asking them questions about like, 'Hey, I saw you were doing this. It looked really cool. Could you tell me a little bit more about what you're doing?'
All those machines come with giant manuals, so you sit there and read the manuals. You don't have to, but it's the best way to learn. … Like, the basics like you do. You don't have to read the entire manual. It's good if you do, but like you have to learn how to use the machine. So, that's how we learned how to use the machines. We went through the manuals. Yeah. … Learning how to use the machines is manuals. That's how you learn how to use machines. There is no other way.
Because everything I've learned, I've learned just by fixing the same messed up extruder on 3D printed four times. … So like you can study a manual on a 3D printer all you want, but at the end of the day until you get in and take it apart and put it back together, that's really the best way to learn it.

Learning Model Application. The insights for considering makerspaces as an "environment of everybody is learning" confirm the back and forth between cultural and content knowledge acquisition. Even more so, this interplay between cultural and content knowledge is facilitated by learning through others as students gain insights into the culture and content through asking for help. Then, the particular acquisition of content knowledge is assisted by learning by doing, which we explore in the next finding. Further, overcoming the fears associated with failure and with asking for help demonstrate a direct link of the cognitive competencies and learning through others towards self-awareness. Also, the ability to be able to see other people's tangible products and learn from that, whether simply for inspiration or content, indicates a connection of the cognitive competencies and learning through others towards ingenuity.

4.4.2 Makerspaces as a "design journey"

"There's some sort of connection between looking at a design and knowing which machines can do it."

This next section seeks to understand the relationship within the content competencies; the focus on content competencies is based on the fact that 1) this work aims to gain insights for engineering design, and 2) the data was saturated with discussing the interplay between the content competencies. The last section began a discussion on the power of seeing other people's ideas in the makerspace. For one participant, they expanded on this concept in recognizing that "it's really interesting seeing people with these really cool ideas and then how that interplays with the more tangible, actual machining of it." She further specifies that "sometimes with my own projects, sometimes starting with knowledge of what can be done on machinery can be really helpful while you're designing." This begins to indicate that the concrete knowledge of the machinery allows for the conceptual understanding and knowledge of design.

The women's narratives strongly support the notion of developing concrete knowledge first and *honing in on technical skills*. Generally speaking, the women sought to hone in on their technical skills as a means to then be able to engage in design and create projects (see Table 5). This begets a give-and-take between design and more physical skills. As a student aims to hone in on a technical skill, then they must think of or create a design to be able to use on a piece of machinery or tool. Alternatively, should a student come in with a design, then they learn more about a piece of equipment in the process of creating the design. Even when the individual is practicing with the same design, they are instilling the sense of "muscle memory" with the machines.

Table 5: Examples of "honing technical skills."

Interviewer: Have you done, you said you did some personal projects? Participant: Yeah, but they were very much honing technical skills.
Sometimes it's, with a sticker cutter it was a just coming up with simple ideas of things I could make so I could get practice on it at first. Sometimes it's just a matter of taking a piece of scrap wood and making a couple of cuts in it and just playing around with it, not really making anything. Just making a blob of wood that has a bunch of practice cuts in it. … Just because sometimes you have to make sure you actually, it's the muscle memory of how to use the machine often. Especially for more complicated things like the lathe probably involves a little more just muscle memory to make sure what does what … It's like using a pencil; you have to practice it at first to make sure you know how to use it correctly.
More just if I have an idea. Or a lot of things this semester have just been little things that I use as a way to learn how to use a machine. The stickers were a lot of just ... Well I made a couple of stickers that were just really just simple images of from a book I read or something, because I needed an idea of something to make as a practice. I haven't made many big things yet, just because I'm getting a lot more use of the space this semester. It's been a lot of helping other people while I'm on shift, which I do enjoy quite a bit.

Table 5 Continued.

I did the training because I wanted to learn how to use all the equipment.
Right now it's just this period of time where I'm just familiarizing myself and making sure I'm comfortable. It's just all trial and error right now, so no major projects yet.
When I came in as a user, I never really came in with a project in mind. More of - a lot of times I would come in with a tool in mind. Like I have this material and this tool, let me think of a project to make on it, while most of the people coming in as user usually have – here's the thing I need to make, how do I get there. And, so it's - you get some of each, but a lot of people - like, there's a – there's a difference between people who see the [Makerspace] as a place to accomplish a task and that it's like a place to spend time and learn things.

While users seek to gain comfort in their technical understanding first, there are instances when a design is used to jumpstart a participant's engagement in the space. However, this is usually linked to either a class-related activity or is dependent upon a person's background, where if a person has a design or art background, then they already have experience thinking of designs. Class-related activities can help to initiate a person's engagement; however, there are a few concerns to take into consideration: a class-related activity that warrants using the makerspace 1) does not guarantee that an individual will gain technical and design knowledge and 2) may actually be detrimental to one's involvement, if the class does not allow for the appropriate opportunities. For the first consideration, clarification is needed. One may read that point and call out that students can be negligent and lazy in their efforts so that would be when the student would not gain technical or design knowledge. Obviously, this can happen, but the first consideration is pointing to the fact that a person who comes in without technical or design knowledge would have an inherent disadvantage that may lead to their inability to seek appropriate resources causing a poor performance, which may lead to the experience being detrimental to their confidence and willingness to make.

This is reflected in one participant's narrative, who even has an art background. She "took [the sophomore design class], and it was horrible. … Like I had never built anything before. I had made stuff, but that's not the same as building anything, and so I had no idea what I was doing." During the course, she tried to build the project, but "things weren't working," and she "wasn't sure why." "People didn't teach me how to build stuff. I just knew that my [junk] was [junk], and it was terrible. I knew that. I was like, 'But I don't know what to do.'" After the class ended, the summer ensued and she "kept thinking about what I could do to make things ... why I hadn't done a good job." So she decided to learn how to sew and bring back some of her art interests, which made her realize that "this is cool and all, but I've already done art. I want to build something. I decided that I wanted to build a clock." To build the clock, she "bought all the materials that I needed, and I started working on it in the [Makerspace]" even though she "didn't know how to use anything." While keeping the mindset that she "want[ed] to learn tools better," she "learned to drill press, bandsaw, sanders, scroll saw."

For another student with an art background, she started with a class-related project that spawned her interested woodworking. Then, "because of the project, and then I was like, 'You know what? I wanna build my own furniture.'" Her art and design abilities were further nurtured and expanded from her interest in woodworking. When asked how she finds ideas, she articulated:

> I think it's just; I have an idea of something that I want to make or, you know, I'll say … I wanna make a plant stand. … but most of the time it's just a vague thing and I pick and pull what I like about different things and put them together to make my thing.

With her newfound interest in woodworking, the participant faces the challenges of "bridging the gap between what needs to be done when you don't know anything of how to do it." As such, she learns how to break down the "communication barrier" of her not "really know[ing] how to explain what you want" to the student workers in the space, and thereby learns "technical jargon," what tools are appropriate for the tasks that she wishes to pursue, and then how to use the tools.

It is through developing these technical skills that *forward one's ability to more fully engage in design* and also have "a leg up for a lot of classes like senior design when you have to build stuff." "Because once you understand how it works and how it functions, then you understand how to undo any mistakes that you made" and you are able to approach projects or problems with knowing whether an idea is feasible or not. For example, "you [may] want to make something that's sleek and cool but to get there, you have to have all these really jank looking prototypes that prove that the functionality will work really." Understanding that process for building a quick prototype can help provide the insights that a student needs in other avenues, such as research or class. For one student who already had experience in the makerspace and was taking a project-based class, she realizes that "because I had like the technical knowledge, I guess, I was able to figure out different things we could build easily." Similar situations occur for when users enter into the makerspace and a woman student is faced with the challenge of figuring out how to help them or what to do:

> This is the fuzzy part, right? A lot of it's just experience. Like obviously when I started I wasn't the most experienced [student worker], so I would sort of refer people on and say, "Hey, I don't really know how to do this." Basically the more you work with the machinery because we have to just sort of keep maintaining them, the more you know what it can do. ... I don't know there's some sort of connection between looking at a design and knowing which machines can do it.

While the woman participant is unable to clearly articulate the connection between design and the technical knowledge, she sees that the more you work with the machines, then the more you can do with that machine and in design. Another student builds out this connection by recognizing that "it's a relationship. It's three ways. So it's the user, the material, and the machine. And you have to interact with each one, how they interact with each other to create what you want, to create your vision." The materials, the machine, and the maker are creating together as a means to move towards one's vision or design.

With moving towards this vision, women students are able to build off of their hands-on, technical, and design knowledge, *moving into a realm of problem-solving, critical thinking, and creativity*. Through the makerspace, the women students are able to "first … learn how to problem solve like here on the table physically, and then I could figure out how I could problem solve more conceptually" showcasing how working through a problem with one's hands influences the ability to think through a problem. Then working through a problem requires creativity, since creativity is "problem-solving more than anything" where "they go hand in hand … like you have to be creative to be an effective problem solver to think of a creative solution." The ability to work through problems and be creative develops through time and experience, since "the further I got in using the [Makerspace] I think I got a lot more creative and how I can get things to work." Through developing these skills and working in a makerspace, a woman student "realize[d] you have to learn how to adapt and figure out what tools can be combined to meet someone's request or find alternative ways to accomplish something." Whether for your own project or another person's project, the ability to adapt is essential towards learning and creating in a makerspace:

> Also, because the machine is down. And I feel like some people in the [Makerspace] are like oh I can't 3-D print it, I guess I just can't make it. Or they're like 3-D print stuff, you can very easily cut out of wood or they will make, like you know, something you can make so easily by hand and they'll still try to just have the machine do it for them. And so, it's also part of trying to have a greater push for like hey even if you don't have an embroidery machine you can still do this by hand. Like, you can't sew a button back on your pants with an embroidery machine, but you can do it by hand and you need to learn how to do that. Like, having hand skills in addition to like the computer and technical skills.

Again, building a repertoire of a diverse set of knowledge and skills (such as the computer, technical, and hands-on skills) feeds into one's "toolbox of design" and allows them to be able to make efficient and creative design decisions. These types of skills are fostered through makerspaces, as women students learn and engage in their "design journey." The experiences that occur when traveling on this journey can be summarized as follows: "So the more I learn about machines, the more projects of people I see come in, you know, the more you think about in the back of your head and sometimes yeah, we'll get there eventually."

Learning Model Application. The data demonstrates the interplay between content competencies, where having more hands-on knowledge with the machines, materials, and computers allows for one to engage in design and then further generate more creative solutions. While the excerpts provided from the participants do not include an emphasis on material and computation knowledge, these remain factors in the building process, because many of the machines require using some form of computational software (such as Adobe Illustrator or Inkscape) and also building requires using materials. Therefore, the material and computational knowledge/skills impact an individual's relationship with the machines or tools. Further, the acquisition of content knowledge and an individual's desire to create a design can result in creative solutions, which confirms the link between content knowledge and ingenuity.

4.4.3 Makerspaces as a "laboratory for creativity"

"There's limitless potential."

Expounding on the creativity aspect discussed in the latter segment of the previous section, women students begin to adopt the perspective that nothing is out of reach and that in a makerspace "there's limitless potential." The makerspace supports this perspective in two main ways: through *opening up doors*, and 2) through *instilling belief in oneself*. Evidenced in one participant's reflection, she emphasizes the coupling of both ways: "I think it just opens up a lot of doors. Like, coming from someone who makes not very practical things, learning how to use the tools was just ... it's dangerous. 'Cause then you're like, 'Wow, I know how to do this.'" It's "dangerous" because now she has the access and confidence to be able to create anything.

One of the values of capturing a woman's narrative through phenomenologically based interviews is the focus on reflective story-telling. Through reflecting on their own stories and journeys into the makerspace, the women share their experiences of how the makerspace "opened up a whole new world of, like, didn't even know these tools and equipment existed because I wasn't exposed to it." In one student's reflection, she realizes that the access and exposure to the makerspace are valuable for classwork, but also for engineers to be able to unleash their "creative freedom":

> The [Makerspace is] great to have for classwork and stuff, but just as like a mode for being able to make products and express yourself, it is so nice to have that resource there. It is so nice. I feel like engineers aren't always able to express themselves in a creative way, and I feel like this is like an engineery way to be able to do that. I feel like in our classes, there's not a lot of creative freedom for a lot of stuff. And I feel like engineers are like, oh, I can't have hobbies. … But this is a really cool way that lets you use your skills that you learn in class to create something and you use that engineering mindset in an artistic way.

As a resource, the makerspace becomes a means to "use that engineering mindset in an artistic way," and fosters the means to pursue creative endeavors. Though, recognizing that creativity in design may be challenging, the makerspace community provides insights for how to open the door to design in that "it's those little ideas that flip through your head when you run into an everyday problem, and that's sort of what we encourage people is like, hold onto that thought, hold on to that problem because we almost guarantee that there's a way to fix it." In holding onto a little idea from a common everyday problem, a student opens the door to the "laboratory of creativity" where there's an "almost guarantee" that any problem can be resolved. Once through the door, "it's just weird to think about" because they'll "spend probably hundreds of collective hours down there and …probably a thousand" in a place "that was a study space, that was a hangout space, that was a workspace, that was a creative space [and] just had so many other purposes" than "just a room full of tools."

The makerspace opens doors for every participant, see Table 6 for five participants and Appendix H for all participants. These doors include realizing that "design is thing I could do," that "I'm more willing to go for tools I don't know," or that one could "use it for your hobbies." One participant describes that she "actually didn't realize how much went into me coming to this point, with like, coming to Makerspaces." Not only do these excerpts show how the variety of doors opened reflects the extensive value that a makerspace brings to a woman student, but they also demonstrate the value of the phenomenologically based interviewing has on one's ability to reflect and realize the impact that the makerspace has had in their life.

Table 6: Examples of how the makerspace opens doors for five different participants (see Appendix H for examples for all participants).

P1	So, like, if I hadn't played in makerspaces and, like, been exposed to, like, cool people doing cool things and, like, seeing other people's passion and then finding my own, I wouldn't know that, like, design is a thing I could do.
P2	I'm more willing to go for tools I don't know, because I've realized how simple it is to -- like, a lot of the tools, like – I never would have thought I would know how to use a laser cutter.
P3	I also feel like if I hadn't had Thomas to, like, open my eyes, to be, like, "You can use this for, like, your hobbies and all that." That I would have thought it was strictly more like a utility school thing, versus, like, you know, make art out of this, or, like, you know, use it for your hobbies and stuff like that.
P4	I now describe myself as a designer and a problem solver, which I think I might have been before, but not in a refined way. Like I didn't understand my process. Like now I understand like, oh, empathy, empathized, defined, like prototype, test, roll out, like get feedback. And that's just like I did that so loosely before, but like now that I understand it as a process, I'm able to do it better. So I feel like industrial design, by putting me in these half tangible, half conceptual places, it's taking my craft and what I learned from my craft and making it a more refined process so that I can be a better problem solver. But I realize now it's so much about space.
P5	Making things helps. Because it takes your mind off. Because you go into like an overdrive zone, because you don't really have a lot of time, but you still have to get something out in that time so you're like not focusing on anything else. It really does help, but yeah. … I actually didn't realize how much went into me coming to this point, with like, coming to Makerspaces.

Once the door is opened, the woman begins to assume the perspective that their visions and designs are more possible, as they come to believe in themselves. One participant expresses, “So it took me a while because I was learning everything, but it was, I think sometimes people don’t know that you really have the technology to say, okay, if I can design something, I can make it, and it’s not impossible.” There is this “power to make something that I want, like I can bring ideas to life," that builds the confidence and feelings of empowerment:

> I started having all of these brilliant ideas. I had confidence that, whatever I was going to think of, it was going to be great. I could make it great. It was going to look good. I knew how to use the machines. It was so empowering. It was the best feeling.

Through knowing how to use the machines and being in a makerspace environment, not only does creativity evolve but also the belief that one can physically create any idea that passes through their mind. The makerspace "definitely help[s] … with the whole creativity side of it" and "when you see you can build things, it's more easy to believe in ideas." In working in the makerspaces, "things are more attainable and less intimidating. Like after getting trained on some of the really intimidating metal equipment that shoots sparks and are really loud and scary, once you can conquer that, you can conquer anything." These bold claims of being able to "conquer anything" are rooted in a "willingness to take challenges and try new problems," where "new problems are exciting, not the end all, not the end of the game" because the students "have had a lot of experience now taking something from idea to solution." Through this experience, the women students are engaging in the design process and building their "toolbox of design," which allows them to recognize the feasibility of their designs:

> I think you might not end up laser cutting for your job, but it's still a mindset where it's like, if you design things but then you never see the manufacturing feasibility of it, you'll never know if it's possible. I could design something super cool, and not

be able to make it. Then what do I do with the design now? That's a really cool side of the maker space, where it’s, I designed something that I'm like, ‘I actually cannot laser cut this because the balsa will just break in half because it's not structurally sound,’ or, ‘I can't water jet this thick piece of aluminum. It’s just not possible.’ Through those things you learn how to modify your design, and so on and so forth. As an engineer everybody goes through this, where you make design changes, or you pick design constraints, and then you try to manufacture it and it doesn't work. You need both sides to balance each other out.

Possibility corresponds to feasibility, which is learned from experiencing and balancing manufacturing and design in the makerspace. Before the makerspace, “if we had this idea, we have no way to test it, no way to really see if it works, so it stays a problem. With the [Makerspace], it’s cool. We have this problem, we’ve got a solution, we can really fix this. Which has been a really, really cool experience to have.” Not only are the students learning how to have an idea and then create the project (that is, the design process), they are experiencing great enjoyment in the process (Table 7).

Table 7: Examples of the vindication and enjoyment of going from idea to a tangible object.

But it was definitely my first experience of like, oh, if I can like, think of this thing I want, I can make it in a week, which was really cool for me.
So I really like the idea of being able to say, you know, oh, this idea isn’t that crazy at all. I know we can make this, or we can get these results faster than we thought, we don’t need to send this off to somebody to do. These are ideas we can take out of the brainstorming stage.
Well, I like being in the shop a lot. And then I like being able to have an idea and then make it happen in real life. Really enjoy that. So now the problem is just coming up with ideas and things I wanna make. So usually I try to make things for presents. Like I think I’m gonna make my mom a picture frame or something.

A final byproduct of being involved in the makerspace and there being “limitless potential” is the assertion that “the makerspace pretty much gives me the ability to contribute in any field possible.” The lessons learned and experiences in the makerspace further help students to *develop an adaptable and transferrable skillset*. The design skills that they’ve learned are applicable to domains outside of the makerspace, such as in research, classes, industry, art, etc. One participant announces that she “could actually go and use these skills in my actual career one day, versus just in the hobby. They’re applicable to like real world life and job.” As evidenced, the makerspace supports learning for women students in helping them to realize that “just because you’re not good at something at some point in your life doesn’t mean you won’t be good at it later on.”

Learning Model Application. While understanding makerspace as a “laboratory for creativity,” the findings helped to showcase how the intrapersonal competencies link back towards both interpersonal competencies and the cognitive competencies. The women students recognized that as the went from idea to solution, then they became more confident in their abilities to be creative, which further confirms the link from content knowledge towards intrapersonal competencies and the link between self-awareness and creativity. Then, as the women students became more confident, resilient, and creative, they were willing to try more designs and machines. In that case, the intrapersonal competencies link back to content knowledge/skills. Similarly, the women students have the confidence and affirmation that they can communicate in any field because of their experience in the makerspace. As such, a link results from intrapersonal competencies to interpersonal competencies. In turn, we have the final model, see Figure 14.

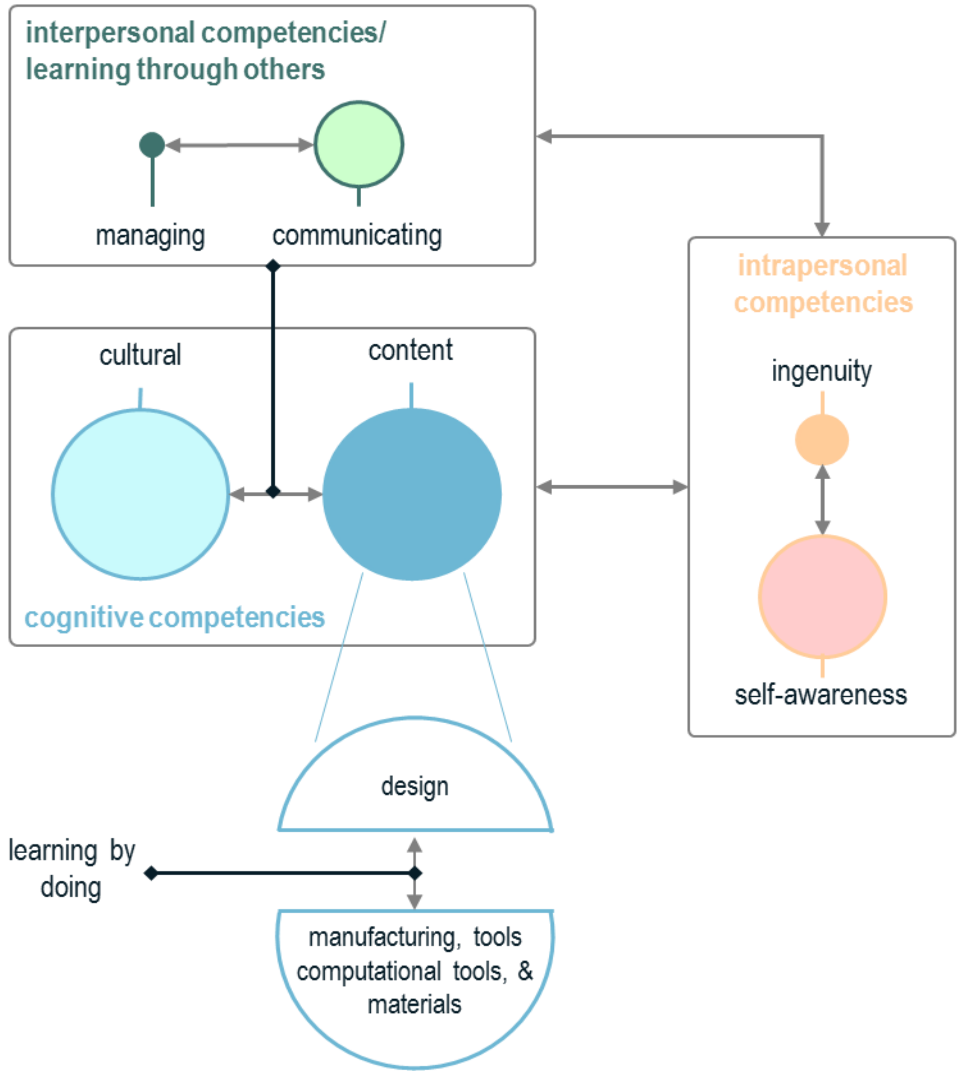

Figure 14: The learning model.

4.5 Discussion

In 2004, the National Academy of Engineering (NAE) emphasized that the Engineer of 2020 should have strong analytical skills, practical ingenuity, creativity, communication, business and management knowledge, leadership, high ethical standards and professionalism, dynamism, agility, resilience, flexibility, and the habit of lifelong learning (*The engineer of 2020: Visions of engineering in the new century*, 2004), which is evidently a high aim to achieve. In the meantime, the number of makerspaces experienced a worldwide increase from 100 in 2006 to 1,400 in 2016 (Lou & Peek, 2016). Makerspaces are seen to provide a means for individuals to acquire certain 21st-century skills (Johnson et al., 2015) and offer opportunities for students to engage in more innovative thinking and produce creative solutions (Bowler, 2014). Through investigating how university makerspaces support both how and what women students are learning along with how they are engaging in engineering design, we articulate the types of learning (both modes of learning and products of learning) that women students engage in, the themes of learning and design that recur in women student narratives, and the interaction between the types of learning (represented by a learning model).

The typology of learning demonstrates that women students are engaging a diverse skillset from being involved in the academic makerspace. For modes of learning the makerspace supports primarily two modalities: learning by doing and learning through others. For products of learning, the makerspace encourages the learning of cognitive competencies (content knowledge/skills and cultural knowledge/skills), intrapersonal competencies (ingenuity and self-awareness), and interpersonal competencies (communication and management). This shatters the notion that makerspaces are only helping students to gain manufacturing and tool knowledge. Women students are learning how to collaborate, how to design, how to reflect, how to problem solve and how to produce creative solutions, which are further expounded upon in the data’s emergent themes:

- Makerspaces as an "environment of everybody is learning"
    - *inviting failure*
    - *supporting asking for help*
    - *engaging learning and inspiration*
- Makerspaces as a "design journey"
    - *honing in on technical skills*
    - *forwarding one's ability to more fully engage in design*
    - *moving into a realm of problem-solving, critical thinking, and creativity*
- Makerspaces as a "laboratory for creativity"
    - *opening up doors*
    - *instilling belief in oneself*
    - *developing an adaptable and transferrable skillset*

Looking to the literature, these findings present a soundboard for existing claims and a springboard into understanding the nuances and learning experiences of all students. For example, Fleming (2015) states that "failure is a necessary step on the road to success and innovation" (p. 9) and that "maker education fosters curiosity, tinkering, and iterative learning, which in turn leads to better thinking through better questioning. I believe firmly that this learning environment fosters enthusiasm for learning, student confidence, and natural collaboration. Ultimately the outcome of maker education and educational makerspaces leads to determination, independent and creative problem solving, and authentic preparation for the real world by simulating real-world challenges" (p. 48). Confirming Fleming's beliefs, this work demonstrates that students are engaging learning and inspiration; developing confidence and resilience; and learning how to work with others and collaborate. In another instance, makerspaces foster the notion that "owning the learning experience opens unexplored horizons to students because independent thinkers have the uncanny ability to strike out into uncharted territory" (Kurti et al., 2014a, p. 20); this is evidenced as makerspaces become a "laboratory for creativity" for students, where doors are opened, they believe in themselves, and they gain transferrable skillset for uncharted territory. The women students "see themselves as learners who have good ideas and can transform their own ideas into reality" (Martinez & Stager, 2013, p. 36), as they are engaging in "creative, higher-order problem-solving through hands-on design, construction, and iteration" (Johnson et al., 2015, p. 38).

Ultimately, Burke provides a clear and well-aligned expression regarding the impact of learning in makerspace: "What is made may not matter at all; it can still influence the thought process, vision, and ability to connect of a learning maker. These abilities can enhance a person's thinking and work in many different fields" (Burke, 2014, p. 13). The makerspace changes how women students think, whether how they think about design or how they think about themselves. Makerspaces have provided women students with the opportunity to explore and engage in learning that they never dreamed possible. Now, the makerspace offers "limitless potential" for women students as they build their "toolbox of design.” While this work focuses on women students at a technology-focused institution, we expect these findings to be transferrable for makerspaces of any style and of any demographic.

4.6 Conclusions

In efforts to understand the how makerspaces support women student learning, this chapter presents a qualitative approach for gaining insights into 1) how and what women students are learning from these makerspaces, and 2) how women students are engaging in engineering design. Using two different interview processes, we developed a typology of learning that characterizes different types of learning that emerge from lived experiences of women students in the makerspace; the typology articulates both modes of learning and products of learning. In conjunction with the typology of learning, we further analyzed for common themes and patterns among the data and identified that makerspaces act as an “environment of everybody is learning,” as a “design journey,” and as a “laboratory for creativity.” Juxtaposing the typology with these key themes, we created a learning model that showcases how design and learning interact in the makerspace. Thereby, makerspaces are confirmed to help provide women students with a diverse skillset, engaging design, manufacturing, cultural knowledge, failure, collaboration, confidence, resilience, communication, management, and ingenuity. Unquestionably, an educational system based in the maker movement can revolutionize pedagogy and learning (Kurti et al., 2014b).

CHAPTER 5. PATHWAYS INTO UNIVERSITY MAKERSPACES

"If we just changed the narrative that girls are a part of design, then it becomes a normal thing."

5.1 Research Question to be Addressed

Because learning is contextualized by education precursors and sociocultural environments, the women students' learning and design experiences are impacted by their pathways into and through the makerspace. Further, by providing access to a variety of resources and hands-on outlets, makerspaces offer opportunities for innovative thought by providing a platform for engineering students to create a community of practice centered around making (Galaleldin & Anis, 2017; Halverson & Sheridan, 2014; Pernia-Espinoza et al., 2017). Overall, this chapter seeks to understand women's pathways into an academic makerspace COP in the context of design and learning, as described through the following research question:

How are women students' design and learning pathways into and through makerspaces developing?

In turn, this research question allows for engaging a broad overview of women student narratives. As a means to narrow the scope for analysis, we examine how women are coming into the academic makerspace COP by investigating the influential factors and barriers associated with their pathway. The emerging themes will allow for the creation of a model that shows the pathways of women students in the making ecosystem.

In efforts to answer the research question, we utilized the methodological approach described in chapter 3 and chapter 4. However, we adopted and adapted the use of grounded theory techniques and coding processes as a means to extract themes of pathways within the data.

5.2 Findings on Women Pathways

When prompted with the request to build a timeline of their making experiences, the women students provided a variety of interpretations (see Figure 15-17). While some started their timelines as an infant, others only focused on the most defining moments of their college experience. Regardless, there was not a single path that constituted the women's pathways into the makerspace, nor were we able to identify a few major paths that summarized the various pathways into the makerspace. Rather, we were able to extract recurring themes within the variety of pathways (Figure 18), where we recognize pathways as "my background of making," as "formative in my journey as a maker," and as "being a woman maker."

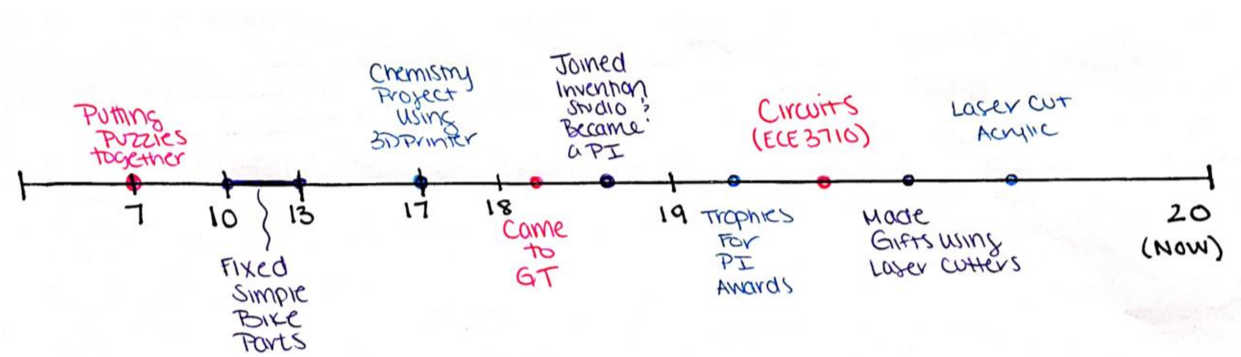

Figure 15: Recreated exemplar 1 of woman student pathway.

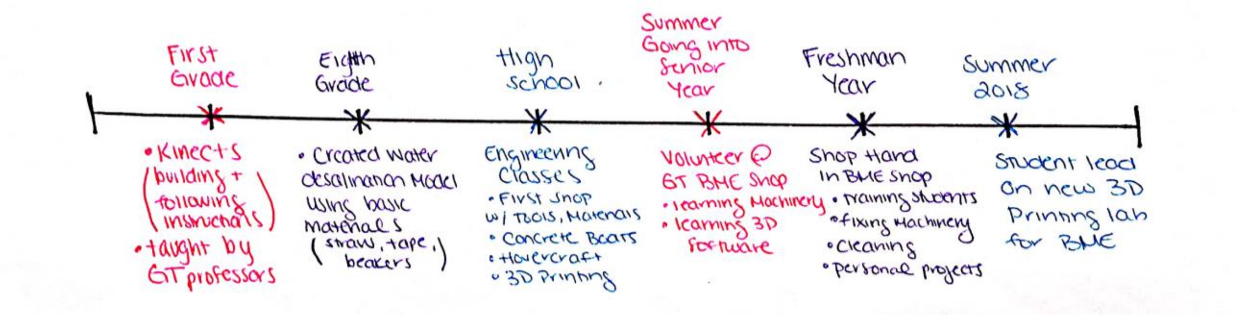

Figure 16: Recreated exemplar 2 of woman student pathway.

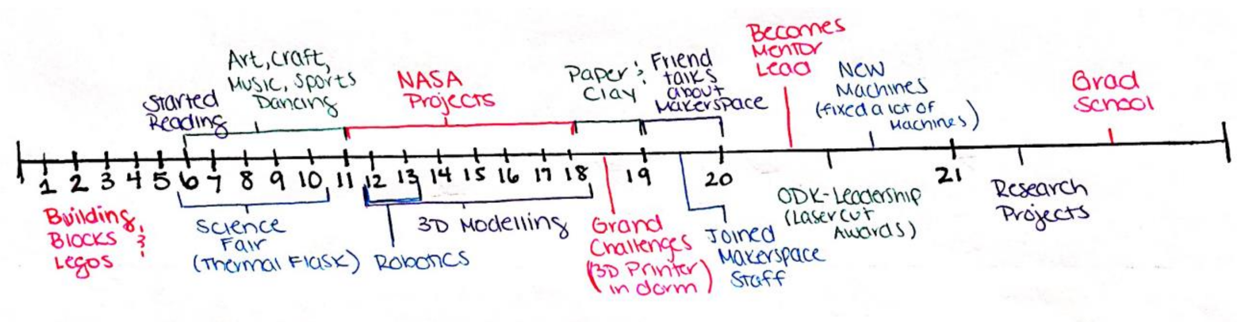

Figure 17: Recreated exemplar 3 of woman student pathway.

Figure 18: Themes of pathways that emerge from the data.

5.2.1 *Pathways as "my background of making"*

The women student's "background of making" highlights their experiences in growing up to before starting their college experience at Georgia Tech. Evidently, there was not a single identifiable set of influential factors that we could argue as reasons for a woman's involvement in the makerspace. However, there were three major aspects to these women's youth experiences that allowed for pathways into the university makerspace: 1) sustaining support, 2) integrating education, and 3) creating pastimes.

Sustaining support refers to when the women students participated in activities that there was some sort of support, mostly from family but also from peers, teachers, etc. One form of support is where family provides opportunities for these women students and encourages them in their interests and endeavors. For instance, one participant talks about how she was not only surrounded by art supplies but how her family always encouraged her hands-on activities.

> My family is like very into hands-on crafts stuff. And so, I grew up with a lot of like art supplies and art materials and tools in my house. So, my mom is really into scrapbooking. So, there's always a lot of paper crafts. And sewing supplies. And then my dad works in, like he does some construction work. He's a contractor. But then, he is also into like building small projects. There were always a small amount of woodworking tools where we lived. … And so like, I guess my first Makerspace was our house and like our dining room. And I often get a lot of flak from my family about, like putting stuff all over the dining room, like totally taking over, like making my sewing empire. … And so, my family is always very encouraging of

> like learning by doing. Yes you can have the supplies, like let's look in the recycled stuff too, like and not ever. I was really never constrained unless there was a dinner party and my mom was like, you should clean up. But as soon as the party is over, you can set back up. Like, we're very, like everyone was very supportive. Even if sometimes they were like [groaning sound]. In their heart of hearts, they were very supportive, which was a huge privilege, in terms of me being able to explore whatever I wanted.

This woman's narrative starts with exposure. Her parents are equally into making whether as a hobby or for work, and they allow her to make the dining room table into her own little makerspace. Later on, this sprouts into her engaging in more making activities and surrounding herself with hands-on outlets. Similarly, during their youth, some participants had a natural tendency towards certain activities. For one participant who grew up in a foreign country where making things for women was underscored by the culture, she recalls that her parents "saw that I was more interested in engineering, and like things like that. So they always supported it. I never had any issues with like the whole confidence thing." In simply allowing and supporting their child's interests, this woman's parents were able to change her narrative and bring her onto a making pathway. Further, it is not simply the parents or adults in a woman's life who make the impact. Rather, peers and siblings can also largely impact a woman's path into making.

> I started playing with wood a lot, mostly because my older brother had had a lot of scrap wood laying around for projects that I would like and we had saws, a ton of saws. … I would just be playing around and I would like cut out shapes with the wood and paint them and stuff and make like funky stuff. I just like making like art

> out of wood I guess so I just start there. Well I don't know about like if it's considered making things, but I would also break apart a ton of things.

From the influence of a brother, this woman takes on making things in her youth. Later on, she ends up attending the same university that her brother attends, and he brings her into the space because her “brother showed me how to use these machines too ‘cause he was just like, I'm gonna need you to help me with this and he's like, you go do this part and I'll do this part.” Herein, support can transform into the form of where a parent or family member is a little more active in their influence so as to provide the women with a broader spectrum of what they are capable of. For instance, the same woman whose brother impacted her start into making also “did do a lot of renovation and construction stuff with my dad and my brother on our house. So that's kind of where I learned how to use most of the tools that I know to use before I got to the shop.” Of a more extreme measure, parents might be more creative in how they actively influence their child’s engagement in hands-on activities:

> Actually, it started with my dad. I got in trouble because I got a B on an exam or something, and my parents punished me. My punishment was to make a computer. I know, it's really weird. … I really enjoyed it. I always was very tactile; I guess the word is. I always liked doing things with my hands, whether it was art, it was reading, piano playing. I always had to do something with my hands. Doing PC building was really fun, and then my CS teacher that same year introduced me to a club called Cyber Patriots, which was a cybersecurity networking club pretty much [and] competition, because she saw that I was really into technology. She was really for women in STEM.

From being forced to build a computer as a form of punishment, this woman starts her pathway into more deeply engaging in making, especially with computers. As a teacher takes notice, the teacher provides more fuel to the woman’s passion by introducing her to a school club, lending towards the form of *integrating education* that we discuss later on in this section.

This next excerpt is short but powerful. “I had always known how to sew because my mom had taught me like this is what you need to know, like hem your pants and like sew buttons back on your shirt. … And she taught it to my brothers as well.” A woman participant reflects on how her mother taught her and her brothers how to sew since her mother believed “you just need to know this stuff.” The practicality of the activity was beyond that of gendered biases that typically go with sewing. Further, the moment for learning sewing transformed this woman participant’s life. She drastically engages in learning sewing, which leads her to want to go into fashion, but later learns of pathways that more appropriately engaged her passions, leading her to the makerspace at the university.

Another drastic change occurred in a participant’s life that resonates with most likely many parents concerns and thoughts as far as what steps to take to change the narrative of women in engineering and expose young girls to the appropriate means for engaging an interest in engineering.

> I liked Barbie dolls a lot, and Bratz dolls. I did a lot of fashion shows for my parents. It gets better from here. My father was kind of concerned. He used to tell me this thing. He's like, "You can, when you grow up, either be the doll, or be the boss of

> the dolls." That's what he used to tell me. I internalized that, but ignored it a little bit. I continued along my way. Then one day I came back home, and all of them were gone. He had given them to my neighbor. … He replaced it with a Lego set. I didn't speak to him for a month, because all I had in my room was this Lego set and some other extraneous toys. I guess a couple weeks later I didn't talk to him, but I was really bored out of my mind. I opened the Lego set. From there the first Lego set was this medieval community street cart thing. I built all these houses and got addicted to it a little bit. I guess all the way to the age of 11, and from there onwards still, I just built a lot of Lego sets. I had a collection of them. I really liked the concept of looking at a final end product, but having all these pieces that somehow went together to build this thing. I was traveling along the path of making and building things, just as a young kid with Lego sets. Lots of them, I guess.

As her father replaced her dolls with Legos, this woman's pathway takes a turn. While later her father feels bad and lets her get an American Girl Doll, she ends up making "a makeshift doll zip line thing" by the end of the day, and in turn, "the concept of building things without an instruction manual started to take root, or get seeded in my mind." What further provided support in this woman's story was "know[ing] that there was a company or a corporation that valued my race and my gender was nice to know. I think over time that's definitely built up to where I am now." Support comes in many forms, not simply from parents, but also the support from society. Through all forms of support, women can feel like they can make a difference and have the power to be able to make things.

On the opposite end, some women did not have much engagement in making, but rather had little exposure to making. In these cases, the women were limited in their exposure to making or did not have the resources to make anything – which is far more common for women of lower socioeconomic status or from a country that lacked those type of resources.

Another influential aspect of the women students' backgrounds is the idea of *integrating education* in their making narrative. This means that the women students had experiences associated with the school setting that influenced their pathway into the makerspace. A largely transformative feature of the education system were the extracurricular activities, such as robotics or Science Olympiad. While at least five participants discussed engaging in high school robotics, one woman's interest started because of a teacher offering her extra credit.

> My teacher says, "I'll give you extra credit if you join the robotics team because we need one girl to be able to qualify for the competition." And I was like, "Sure, okay." Extra credit is extra credit. I joined robotics. … So I fell in love with robotics very quickly. Became president, and then I served as president for three years. Won some awards, and just was receiving a lot of positive reinforcement for getting involved in STEM. Tinkering, physics, robotics. … And then we went to the world championship, which was just awesome, that's still in here. World championship. That was to this day the best day of my life. So great. World championship. We didn't win, but we placed [#] in the world, which is good for the world.

In trying to get extra credit, the woman participant falls in love with robotics. She further invests time as president and feels support for her efforts by others and by the validation that comes from doing well in the competitions. For another woman participant, her interest started in middle school with the prompting from her brother: “Back in elementary school, I wanted to be an artist. Then sixth grade, I get involved old with my older brother's LEGO robotics team on the condition that I don't have to touch the robot. By eighth grade, I am captain of the team and fixing everyone else's programs.” Strangely enough, this woman goes from wanting to be an artist and not wanting to touch the robot to then becoming captain of the team and even later helping to start the robotics team at her high school. This set her on the path towards integrating both art and science as a means to make things. However, sometimes, robotics teams may be more adverse than helpful to a woman’s pathway. For instance, a mentor on the high school robotics team “was very old-fashioned, like, "Girls can't do anything." And so, like, I had a really hard time getting started because he, like, didn't trust me in the lab.” Still, the next year, the woman was in charge of the build team, which “was awesome, as well as fun.”

Another woman had some negative experiences in her high school robotics team which lead her to seek another hands-on outlet in her “school's Science Olympiad team. That was the place where I think was the most formidable time between 10th grade and 12th grade. For the first time, I saw a bunch of females in my club that were doing hardcore engineering stuff, hardcore biology, hardcore chemistry. Everybody had a supportive environment.” Again, the support that comes from educational activities helps forward a woman’s pathway into making and makerspaces. Not only did Science Olympiad provide this woman with a hands-on outlet, but she could also see other women working in the science field. In a way, this gave her validation and support for the work she was doing. Further, “Science Olympiad gave me was the chance to make mistakes and explore new prototypes that might fail. It's okay, because that's part of the process of learning.” Here, integrating education allows for support in failure and mistakes. However, it is important to note that not everyone had these types of experiences in school, which later they found as an impediment towards their ability to make. Or, sometimes the experiences were lacking that made women feel less legitimacy in entering into the makerspace.

Lastly, it is important for women students to be able to *create pastimes*. Nowadays, it becomes easier to place a child in front of a television as a means of distraction. There is great power in being able to allow the young to create pastimes through engaging activities. Most of the women talked about the activities that they were involved in, such as reading, building with blocks (e.g., Legos, Kinects, etc.), sewing, painting, soldering, weaving, pottery, knitting, crocheting, graphic design, photography, and woodworking. Of most importance comes the commonality of arts & crafts in the women's narratives. One woman attributes her involvement in the makerspace towards having a heavy involvement in art during her youth:

> The reason why I'm so immersed in the [Makerspace] right now is because from fourth grade on 'til 12th grade I was involved heavily in art. Not because it was something that I was going to pursue in the future, but because I just thoroughly enjoyed it. It wasn't as big of an involvement in my life after, say, 11th grade because ... or no, just high school in general because I went to an ivy school which is like international baccalaureate so they were STEM, STEM, STEM. Then they were let's toss the creativity away. This is where I just got involved with it.

Through engaging in art in her youth, this woman feels that it is what brought her into the makerspace, as a creative hands-on outlet. However, the art is tossed away as she enters high school, which is not uncommon in the women’s narratives. While in their younger years they play with toys, build things, and make arts or crafts, their pathways change with integrating education, creating a tension between *creating pastimes* and *integrating education* themes. The challenge remains to affirm women in their creative endeavors while also supporting them in engineering activities. The support for creating pastimes with arts and crafts can later help with women students to communicate their ideas and prototype. For instance, after doing “a lot of cardboard art, which was fun,” a woman student “got very adept at working with cardboard. Then we used it a lot for robotics, for just initial prototypes of figuring out what might work. … So making something out of cardboard is a very easy way to just communicate your ideas clearly, and also be able to do some initial testing to see if they work.” Through a pastime in creating cardboard art, this woman learned quick strategies into effectively communicating her ideas. Creating pastimes in women’s youth is important because “when you're younger, you don't have a phone or a bunch of friends or whatever. You're a young kid watching your parents do stuff. I feel like you think more about how you would do it. You have more time to sit and chill and think.” Thereby, sitting and thinking and engaging in an assortment of activities helps to “activate your brain into doing things that are creative.” Even if “in my mind that was art,” when “it was mostly junk,” helps to forward a woman’s pathway into the makerspace.

5.2.2 Pathways as “formative in my journey as a maker”

Once at the university, women’s pathways become tangential to the makerspace as they all come to the various makerspaces in some manner. While some have a more immediate entry into the space and others come to the space in their later years, there is consistency in the importance of 1) recurring catalysts, 2) providing immersive opportunities, and 3) affirming encounters.

By *recurring catalysts*, we are describing how women experience recurring situations or encounters that bring them in contact with the makerspace and that draw them into the makerspace. For example, a woman student had multiple encounters with the makerspaces on campus that gradually engaged her pathway, but it was not until a design class that she was finally set on being involved in the space.

> I had friends who were ME and I heard them talk about it, so ... one of my ME friends showed me the [ME Makerspace] and showed me how to [3D] print things. And then ... the [BME Makerspace], I didn't hear about until like sophomore year. But then I had to laser cut some stuff [in the summer for research]and then my friend started working as a [student worker] there and then I ended up spending a lot more time there and I really liked it. So then I started getting trained on all the machines and then decided I wanted to be a [student worker]. Because I was spending so much time there anyways, I figured I might as well get paid.

While she was introduced to the ME Makerspace by a friend in her freshmen year and learns about the BME Makerspace her sophomore year, it is not until the summer after her sophomore year that a research project and her friend being a student worker bring her into the makerspace. Then, her involvement is further sustained by having a class that utilized the space. As such, this woman endures a series of recurring catalysts the prompt and sustain her involvement in the makerspace. The same experience happens for another woman participant where she “3D printed a couple of fun things, just because one of my friends … was like, oh, yeah, we have the [ME Makerspace], … And like you should go check it out, just like bring your file in like STL form and you can print whatever." However, it is not until her third year "that design [course] we got more exposure to the [makerspace]."

Alternatively, some women seek out hands-on outlets upon or before their arrival to the school. When they are seeking hands-on outlets before coming to the school, the online communication/media and the tours during a visit become crucial to their making pathways. Even more so, some women who were not seeking out the makerspace initially can recall being exposed to the makerspace either from their research on the university or the tour that they took before enrolling. For instance, while a woman student met the [Makerspace] club during her visit to the university, she first tried to get involved with a more craft-oriented space on campus, but after finding "them really restrictive in the way that … was expensive to do stuff there and the staff, they were nice, but they were kind of hands-off," she turned to the makerspace. However, when she "initially walked in the first time, it was pretty intimidating - the water jet was scary. I was worried I was going to break things … and, then often times I would come in and it would be too busy, and so I kind of got turned off by the fact that it was busy for a while." It is not "until I kind of learned the ebb and flow of the times and kind of how it worked. But, it took me coming with like [my friend] after hours and him being like, let me teach you individually how to use these tools and how to make something cool and how to like, and kind of how to like really experience the studio rather than just kind of being thrown in. Cause just being thrown in with a scrap pile was still a little bit scary for woodworking, cause it wasn't something I'd done before."

The women students do not necessarily realize the potential and opportunities that the makerspace can offer to them. While a background in making can lead to searching for hands-on outlets, it does not guarantee immediate engagement in the makerspace. Even so, there can be catalysts from before their starting at a university that can provide a more direct path into the makerspace. One student with an extensive making background received "an application form. I applied for that before the school semester started. I got an email from the [Major] listserv. I applied to the Google form. The first week of school they called me in for an interview." For another woman student who describes not having much making experience, she "volunteer interned at the [Makerspace]" during the "summer going into senior year" because a family friend got her the job. Then, she enrolled at the university and began her work as an official student worker in the makerspace.

Engaging in these types of roles in the space leads into the next formative aspect of a woman's student pathway, which is through *providing immersive opportunities*. There are numerous ways in which a woman can become immersed in the space, whether as a user, a student worker, an executive position, or a project lead. Immersive opportunities for the user may come as personal, research, or class-based projects. After taking a design course, a woman student engages in a more entrepreneurial pathway into using the makerspace, and then "for capstone, I think I spent, I know at least leading up to capstone expo I was in the basement for 133 hours of the 150 hours leading up to expo. I literally lived there." Her immersion in the space throughout her college path allows her to not only feel comfortable spending hours in the space during her senior year but also in that "all the things I am most proud of that I did at [University] were because I used these makerspaces."

Providing these immersive opportunities at the university level can drastically impact a woman student's pathway.

Moving beyond the role of a user, women students who are given the opportunity to engage in more meaningful responsibilities in the makerspace can gain more legitimacy as they continue in the making pathway. In taking on more responsibilities, women students are able to "ma[k]e the most change" and gain respect from peers, faculty, and staff. "So I had like a lot of respect from the faculty and staff, and I think that got represented in how the students saw me, like other students. I realized that people had a lot of confidence in me." This confidence helps to further one's investment and enjoyment in the makerspace, for confidence and support goes a long way for engaging women students. For instance, when asked how the experience of being a student worker in the space impacted a participant, she responded that "It's really, it gives me a lot of self-confidence to be an expert in an area of something I'm really interested in, and that not a ton of people or an expert in."

Further, basic immersion comes from creating meaning. Where "if I'm just creating something as a job, like someone's handed me something and is like, "Make this," I'm not going to be as invested in it as if I'm making something for my grandma who's like going to put it on her mantle for three years." Recognizing that immersion starts with meaning helps to engage women to be "super into making" whatever it is that they are making.

However, starting the immersion into the makerspace takes root in *affirming encounters*. As a woman student starts to engage in the space, it is important that what they are doing is affirmed, whether from a person or from creating a successful project. For instance, 3D printing offers an easy and tangible result that can provide a first step into the makerspace.

> Like, “Well, I'm pressed for time, so I can't really come in the shop.” I'm like, “Well, why don't you 3D print it and see what happens.” And then they can just drop off a 3D print. They put zero work into it, come back in a day or two, and it’s done. And they're like, “Wow, like you can make things.” And then that's -- I think that's why [the faculty-member] calls it the gateway drug is because you can just make something from literally putting zero time into it at all, by pulling down a file that you think is cool, and making that.

Through 3D printing, students are able to get a taste of what they can do. Further, as students see what they are capable of, this affirms the responsibilities of the women student workers in the space: “And they'll be like oh, like seeing the, ‘Oh, [wow]. Like this is awesome,’ is like pretty fun part of my job.” From seeing how users are experiencing the space, the women student workers are further affirmed and empowered in their pathways. This affirmation is further engaged by the community of peers in the makerspace, which can lead to “one night that was incredibly formative in my journey as a maker”:

> The reason I say it was so formative is because I hadn't really used the laser cutter prior to that. I'd gotten trained on it. Gone through it once. Kind of knew what I was doing. I've done it a bunch of times with [my friend] but I'd really never done it by myself. … What I did, courtesy of [my friend] almost, because she taught me how to do this, or she gave me the idea, I put my picture in Microsoft PowerPoint. There's a setting for colors on it. You can change it into black and white. Literally

> just black and white. Not a grayscale. I did everything in there and then uploaded it to the computer. It was already in black and white. I didn't have to do anything with the bitmap. It was all good to send off. I taught [the student worker] something. He was like "Wow. I've never done that before. That's the easiest thing I've ever seen."

The formative aspect of this woman's story comes from her teaching a student worker a technique that he did not know about. In her first experience with the laser cutter, she is affirmed in her abilities to be able to make a successful project and also be a valuable member of the makerspace community. Therefore, the community affirms her legitimacy as she moves into the membership of the community. She now has something to give to the community that has been giving to her. Ultimately, it is through "getting good feedback that makes you more excited about it, to keep working."

5.2.3 Pathways as "being a woman maker"

Embedded in the women student narratives are the consistent themes of "being a woman maker." While already alluded to in previous excerpts, there are consistent instances where women experience some demeaning or unsupportive interaction in regards to making due to their gender. This creates numerous barriers for women entering into a makerspace. While overcoming these barriers has framed the women's pathways, they recognize two vital actions that could make for fewer gender biases in the makerspace and making ecosystem: 1) embracing inclusive making, 2) changing the narrative, and 3) engaging support.

Through *embracing inclusive making,* the notion of making is not centered on more masculine activities of welding, woodworking, etc. Rather, making is embraced in all forms (O'Connell) which not only brings value to the arts and crafts that so heavily dominate women's past experiences but also demands respect for all making activities. When asked to speak more on her maker identity, one participant responded with:

> Yeah, I mean it's -- I'd say crafting and making are similar, but it's just kind of a different kind of feel? Like, you're not really going to do collaborative crafting projects, like, you rarely have, like, two people sewing, like, one thing. Or, like, making cards. It's just not -- I don't know, I really can't pinpoint the difference other than just, like, the way they feel. You know what it is? Crafting's all girly stuff. Making is all – hmmm… I want to think about that now, because I -- there's got to be more than just kind of, like, the gendered part of it. But, that's definitely what it feels like. … Crafts your mom would do, quilting, card making, like, knitting, like, stamping and scrapbooking and origami and the kind of smallish stuff, like flower arranging and, like, painting, which at that point kind of flow into more, like, artsy stuff. Where it's just, like, art for the purpose of being art.

While there may be a different feel between crafting and making, the difference causes tension towards including crafting and art in the making culture. Women are taught that crafting and art are not given the same status as 'making' activities. The maker culture emphasizes the same connotations, where at Maker Faires "those guilds and those spaces are pushed off to the side, and they're not at the center in the same way that like the pyrotechnic sculpture group, which is like almost completely male, is the center of the pavilion." These are far from resolved in the university setting, where "even the embroidery machine was in a different room in the [Makerspace].” After one makerspace at the university integrated a specific space for crafting at the entrance to their space, other “people are like, ‘Oh, wow. It's very popular. Yeah, I want to learn it. I want to learn just that part that I need exactly right now, and I just don't respect it, because it's not a real form of making.’” This is further expounded upon as one participant discusses the disrespect towards the sewing machine:

> That poor machine. It's so, it's so finicky and it's so hard to. It's so easy for something to go wrong on that machine because it's so delicate and I feel like there is this mentality of like oh it's just a sewing machine, like whatever. It's like not a real machine or it's not really part of a Makerspace and people try to use it without understanding how it works. Which like, I don't think people would do with band saw because a band saw would like cut your hand off. But I feel like that meant, like that's missing when people, when some people approach an embroidery machine. I don't know if they treat it with the same amount of respect as they do other machines. So, it kept, it got broken like several times in a semester and would stall the projects for like weeks at a time.

The disrespect towards arts and crafts is a long-lasting storyline that continues to infiltrate the making culture. With university makerspace not immune, women students are further having to fight for the respect of their activities. The arts and crafts can be equally important, if not more, than the more traditional forms of making. For in arts and crafts, women students are able to engage in creative avenues.

> Just having that background in art is opening so many doors for me in terms of aesthetics and design in projects and stuff, and it's a huge advantage when it comes to making anything look better. It's years of practice that I have on people if they are not familiar with it. It's something that is hard to learn as opposed to woodwork where these are maybe a step-by-step on how to do it. Art, there's no step-by-step. You can learn to paint through a class maybe, but it's just ... I don't know, I feel like it's more ... there are just two different ways of learning them.

While this participant recognizes the value in her art background, another participant who had a heavy arts and crafts background states that “We can't really say that art has much purpose, but I guess it serves its purpose by utilizing scrap wood, maybe?” Even though later she says that art “has really simplified the design process … when you come up with those different possibilities, it’s easier just to see it in your head.” The notion that art is not valuable contribution to the making community needs to change in order for women to have more access and more legitimacy in the makerspace community. After reading the statistic that 81% of maker culture is male (Make/Intel, 2012), one participant exclaims:

> I read a comment this morning stating that maker culture is 80 percent male and had to laugh. Only if you discount the millions of women sewing, knitting, weaving and more. But, oh, right, they're just crafters. The artificial distinction enrages me.

By including arts and crafts in making, we begin the process for *changing the narrative*. Women are capable and competent. There continue to be instances where they are left to be the “documentation girl” on a hands-on team or where they have to prove themselves in every aspect. These continue to create barriers towards their presence being accepted and acceptable in the makerspace community. “If we just changed the narrative that girls are a part of design, then it becomes a normal thing.” However, when being in the makerspace, men are “always surprised by it when they see it is the thing. Yeah. It's not much less that they're like women shouldn't be in here. They're like, ‘Oh, there's a girl in here. That's interesting.’ When you see an animal get lost in the zoo in, like, a different pen, it's like that.” While there can be confusion over a woman’s presence in the space, there can be instances where women who are student workers are faced with being seen as incompetent.

> But if they come into this space, they'll mostly be like, they'll go ask the guy on duty, or they'll just--there were two people that I had to particularly deal with last year, where they just wouldn’t listen to me, at all. And then we had to get [a faculty member] to come and talk to them. And this guy was very much like--I don't think she knows what she's talking about, because like, yeah--and [the faculty member] was like, "You listened to [the male student worker], but you wouldn't listen to her, what's the problem?" He's like, she's a girl. How can she know how to use a hammer?

While this is an extreme instance, the notion that women are not knowledgeable in making is not to be ignored. Across the women’s narratives, there were recurring instances showing that “there's a lot of the times people are like if there's like me and another male [student worker] there, they'll be like, oh, good to him first. That's cool. But that always happens.” These women recognize that “there is definitely this big conception that like the machines are for the guys.” However, they also come to learn that “some people have the mindset that some girls just don't know what they're doing, especially when it comes to these kind of more hardcore per se tools. It's important to keep in mind that boys also don't know what they're doing sometimes, and it's something that it's just gender bias in society is that we're just perceived to have less knowledge when it comes to this sort of stuff.”

The gender biases in society can also play a role in how women engage in making through classroom activities and in club activities. For instance, for course-related projects “a lot of times we'll see guys come and say, ‘Hey, I'm the person in charge of machining for my project.’ Even if the team is 50 guys, 50 percent girls.” While “it’s just kind of old fashioned,” “a culture where because the guys were so full of themselves and confident, [women feel] a lot less willing to ask about things [they] didn't know how to do. So it was a lot harder to learn those things.” In one class, the women students wanted to come together in the group so as to show what they could do. While they struggled with the first milestone for the class, they persevered despite the disrespect from the male peers:

> Boys just snickered because they thought it was just hilarious that girls would band together like that thinking they had a chance in the big competition. It was just so frustrating. By the end of the summer we had put in so much work, so much more work than the guys, because they've just been relying on all the experience that their dads had taught them and just boys being boys they knew how to do things. They were just not even putting in extra effort. With all the extra effort, we ended up tying for sixth in the competition, and it was the best moment ever. Not that it was first, but we were so excited. We were second in the class. It was so much fun.

Therefore, in order to change the narrative, women students need *engaging support*. While not described in the above excerpt, the women students found supports in their professor who “was able to just ground us and make us believe that this was our strength. The thing is once you feel like you have a disadvantage, that becomes your advantage just because you put in so much more effort." For even when women feel "always very supported, and the guys in my class are like my brothers," it can still feel "like I knew I was alone, and it would be weird if I was working on a team, on a group project with all the other guys, and there's never the girl." There comes a need to allow women to feel support from other women peers. In this way, there becomes "lots of cool women doing cool things in my life. I never had that and that's so important to like validate the fact that I want to do that."

Similar to the fact that women will avoid makerspaces because they are dominated by men (Faulkner & McClard, 2014), "outside of the classroom, there's still a lag for women to feel more comfortable in environments like the [Makerspace] or a makerspace like that. … because women are more prone to not go somewhere they don't think that they're qualified to go, where a guy would go somewhere if they don't think they're qualified to go." This indicates that there is a tendency for women to feel invited towards a makerspace. They woman participant further expresses that a woman would say "I don't think I'm invited. I'm definitely not going" whereas a man would be "like, 'I don't know if I'm invited. I think I'm gonna go anyway.'" These statements continue to confirm the need for support in a makerspace environment.

One final aspect to changing the narrative is that it all starts in a woman's youth, both at home and at school. While one woman had exposure and encouragement for making things, she found that:

> The only thing that sort of taints the water, my parents showing me creativity, is I would always ask my dad to show me the car. Whenever he would fix something,

> I would come in and be like "How did you do that?" He never wanted to show me. This man is like 69 years old. He's sort of a product of his time. I think that if I had been born a boy, he would be more inclined to be like "Come out here so I can show you how to change a tire." I was like "Come on. I want to." He didn't really think it would be something that I would actually want to do. Sadly, no tire changes.

Parents play an extraordinary role in shaping and forming a woman student’s potential. Many women felt underprepared for taking on and engaging in the makerspace community. While efforts are made to provide opportunities for young women through the educational system of youth, this cannot be seen as a bandage over the root of the societal gender biases. For the high school robotics team, a woman student realizes the challenges that she is going to have to face as a woman in engineering.

> They came and completely cannibalized my exterior structure. I didn't know about it. I came back the next day and it was completely gone. I was like, "Oh. This is what it means to, I guess, feel what people say is being a female engineer and not having people take you seriously." If I had to pinpoint an example.
>
> … Then a follow-up to that story was that same team then accepted me into their team. I was part of the big boy club the following year. I was like, "Okay, I think I made it." Their apology to doing what they did was accepting me into their team. Initially, it was pretty good. But then I realized over time that I just became their documentation girl. I was on their team, and I was the front that whenever judges would come to us they'd be like, "Look, we have a girl on our team! She represents diversity and inclusivity." But behind the closed doors it was more I would watch

> and see them doing things, but I never got the chance to dive in head first. I wanted to make those things. I wanted to learn, but they never gave me the opportunity to do it.

While there are gender biases in the making culture, there have been great strides to make women feel more welcome. As more women come into positions where they can make a change, they are advocating in healthy ways that do not diminish the value of their male peers, but rather provides support for all individuals. The women students who participated in this study recognized both the hardships that come from being a woman in an engineering makerspace, but also the value and joy that comes with it. The narrative is changing as women students who are gaining legitimacy and membership into the makerspace "haven't really noticed any differences between how the guys and girls interact. Which is definitely great, because it means there isn't much difference."

Ultimately, "it's really nice that we're encouraging girls to go into STEM because they're just not familiar with it, but it's also not nice to make them feel like it's something that they should be doing." "It's really important to know that if a woman comes into the space, then she's still welcome there. She's allowed to be there; she's allowed to make things in there. To also know that even if a woman messes up in that space, or makes a mistake, then it's just another learning experience and has nothing to do with gender."

5.3 Pathways in a Making Ecosystem Model

Through analyzing the interview data for emerging themes, we are able to build out an understanding of how women student pathways are a part of a making ecosystem, which we use to create a pathways-ecosystem model (Figure 19). The model separates a woman's path from before their enrollment into the university of this study and their experiences before this university, whether that be in at another college or during their youth. The influential factors or barriers of a woman's youth or at another college guide their pathways at the university. While commonalities exist between what influences a woman student's pathway, there are many diverse pathways into the makerspace. Further, the pathway into the makerspace depends upon numerous overlapping experiences. While barriers may impede the pathway, some catalysts helped to keep the woman moving forward. This raises one large limitation of this study: we focus on women who showcase involvement in the makerspaces and not women who do not become involved. Therefore, women who are not involved may have the same influential factors which acted more as barriers to their entry into the makerspace. However, that was out of scope for the purposes of this study. We aimed to focus on the woman who broke down barriers and became a member of the university makerspace.

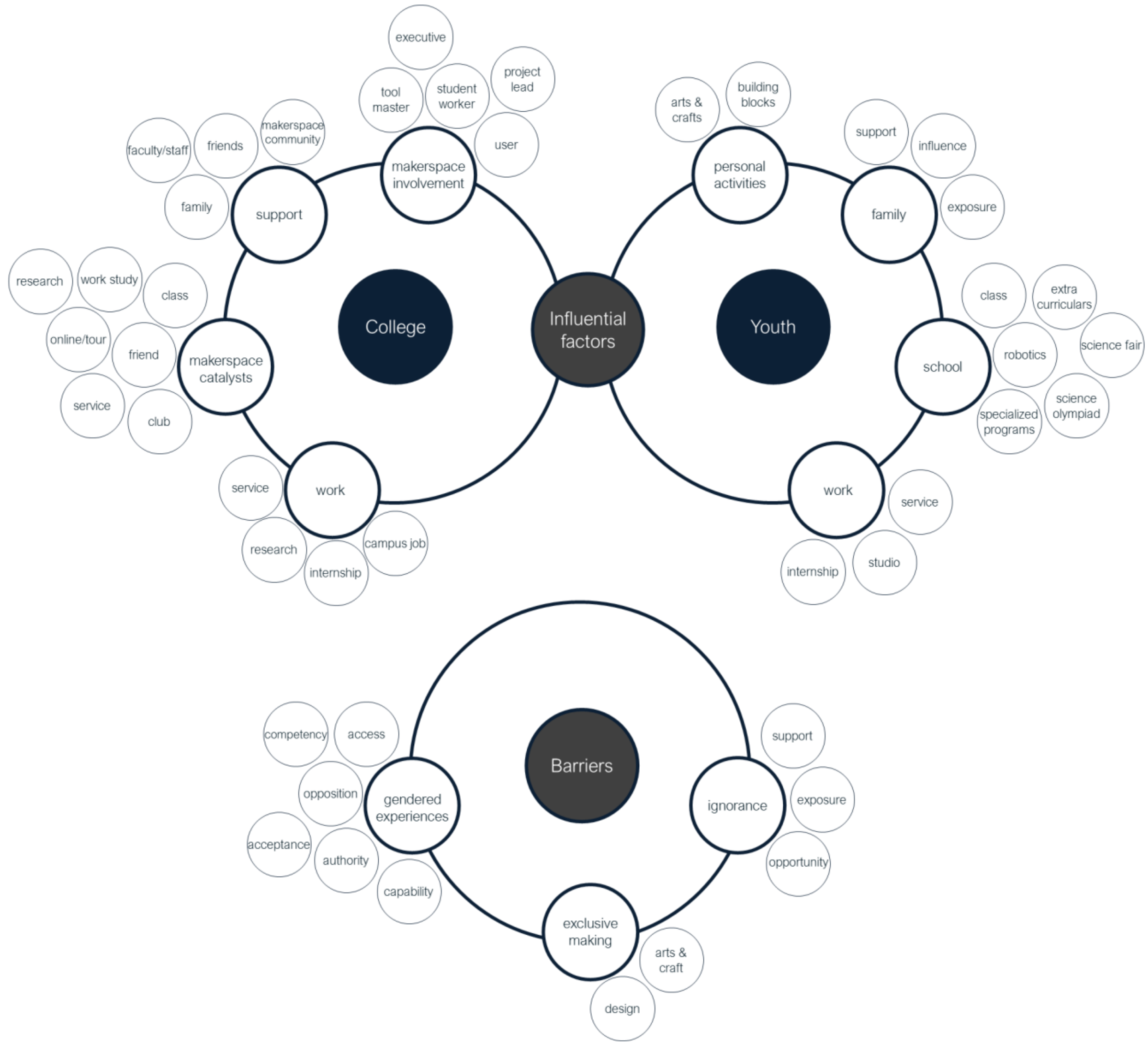

Figure 19: Pathways in a making ecosystem model.

5.4 Discussion

Because communities of practice are rooted in a socio-cultural context, “the cultural richness of this broader context generates a fluidity and heterogeneity within and beyond communities” (Handley et al., 2006, p. 641). This type of fluidity between communities suggests this type of ecosystem among communities where participants navigate their legitimacy among each community. For example, while a woman student navigates a high school robotics club COP and gains legitimacy, this does not guarantee the same level of membership and legitimacy in a university makerspace, where the culture and rules for legitimacy are different. However, her previous experience allows for movement into the university makerspace. Regardless of previous experiences, women students are coming to the makerspace. Their experiences are wide and varied, yet they are navigating their way throughout a making ecosystem in a recurring cycle of catalysts and barriers.

These catalysts and barriers occur at the university level and in a woman's youth. At the university level, friends, classes, and campus jobs afford access and legitimacy for using the makerspace, where women encounter opportunities to further engage themselves in the different equipment and design activities. The makerspace allows the union between art/design and manufacturing/tools. Women take on new roles that help them encounter creative outlets through making and innovating. Through the makerspace, women can gain support and respect that validates the work that they are doing, despite the inherent gender biases that at times, can physically manifest themselves in demeaning encounters. These women's pathways are changing the narrative for women in design and are shaping the future to show newcomers that they are valued regardless of gender, race, ethnicity, or socio-economic status. The diverse entry and pathways through making show that people can come into the makerspace with a lack of background in making, but can still grow into the community and build a repertoire of making skills. These types of people have different barriers than those who come in with a greater making background. No matter, all women have barriers that they must overcome and all women have the potential to become that influence for other women.

5.5 Summary

In previous work, our research team presented preliminary findings showing that friends and classes at the university influenced a student's choice to spend time in a university makerspace (Hilton et al., 2018c). In this chapter, we focus on the making narratives of twenty women students and seek to understand the multitude of precursory factors that influence a woman student's pathway into a university makerspace. To do so, we implemented a phenomenologically based interviewing approach to gain insights into the lived experiences of women students. From analyzing the interview data using grounded theory techniques, we crafted three major themes of pathways:

1) Pathways as "my background of making"
    a. sustaining support
    b. integrating education
    c. creating pastimes
2) Pathways as "formative in my journey as a maker"
    a. recurring catalysts
    b. providing immersive opportunities
    c. affirming encounters
3) Pathways as "being a woman maker"
    a. embracing inclusive making
    b. changing the narrative
    c. engaging support

Through these major themes, we were able to craft a model that illustrated pathways into a making ecosystem. The insights from these pathways demonstrate that formative experiences in women's youth can either positively or negatively impact the ease of the pathway into a university makerspace community of practice. It is important to ensure that initiative for women in engineering education show value towards arts and crafts, provide support and appropriate mentorship for women, and allow for diverse interests and pathways.

CHAPTER 6. BEST PRACTICES

Making a Makerspace

6.1 Research Question to be Addressed

In order to integrate the maker movement into the classroom, this demands a shift from the tradition lecture-based approach into a more innovative environment that fosters creativity and collaboration (Donaldson, 2014; Papert & Harel, 1991b; Schön et al., 2014). Kurti et al. (2014b) argue that crafting the education system with roots in making will drastically change pedagogy and learning. While our previous efforts (chapters 1-3) have focused on understanding the learning that takes place in a university makerspace, we shift the focus from the student perspective towards understanding another perspective (those involved with establishing a university makerspace) so as to then provide valuable insights for engineering design.

This chapter aims to extend the current set of guiding principles through in-depth interviews with members of eight academic makerspaces – each initially chosen due to a belief that they were uniquely different from each other. In choosing these eight makerspaces, the goal was to identify spaces where the stories would likely represent different paths to success so as to better capture the breadth of experiences.

Building on the work for understanding best practices for makerspaces, this study aims to understand the narratives for beginning a makerspace; this aim is addressed in the following main research question:

What are the best practices in the formation of an academic makerspace?

The main research question is further expanded into four focused research questions:

- What was the origin for the makerspaces?
- What are the sources of funding?
- What does access look like?
- What are the management models for the makerspaces?

To understand how success is achieved, this chapter seeks to understand the beginning narratives of engineering-based academic makerspaces at higher education institutions, as described from the perspective of those who played a formative role in the development of the university's makerspace. The beginning narratives of eight various university makerspaces are investigated for the best practices (or shared strategies) in the formation of a university makerspace. This chapter presents a semi-structured interview protocol focused on the topics of culture, access, design, and unique aspects to the makerspace, where nine leaders from eight U.S. university makerspaces participated in this study. Through interviews, the participants have the opportunity to share the struggles, strategies, and insights involved during the formation of the makerspace. Then, the interview data were analyzed for major emergent themes and supplemented with makerspace profiles that summarize how each space got started. We also offer a comparison chart that reports the type of institution, funding sources, access, and management models. Through juxtaposing the makerspace profiles with the emergent themes, this chapter provides transferrable insights regarding origins and best practices for makerspaces.

6.2 Semi-structured Interviewing Method

This study utilized a qualitative approach focused on a semi-structured interview protocol. The researchers adopted interview techniques used in an ethnographic interviewing approach, as a means to engage the participants (Spradley, 1979).

6.2.1 Interviewer

Since interviewing is a conversation between the interviewer and participant, it is important to provide information regarding the interviewer(s). In this study, there were two interviewers involved. The first was an expert female qualitative researcher. The female qualitative researcher conducted the first interview as a model for the second interviewer, a male graduate student researcher in training. The interview conducted by the female qualitative researcher was a means to train the male graduate student, which was the only interview conducted in person. For the other seven interviews, the male graduate student conducted them via an online system (Cisco WebEx). The male graduate student interviewer was in his early 20s and had a Bachelor's of Science degree in Mechanical Engineering.

6.2.2 Participants

The participants were selected based on their involvement in helping to facilitate the establishment of a makerspace on their respective campus. Nine leaders of eight university makerspaces were interviewed; for one interview, two leaders from the same makerspace were interviewed. An initial list of university makerspaces was generated based on a collection of contact information via relevant conferences and web searches.

The participants were selected based on having a makerspace in existence for at least one year and invited to participate through email communication. This process resulted in eight makerspaces housed in the engineering disciplines and six of the nine participants being engineering faculty members. The other three participants consisted of a third-year engineering student, a lab manager, and a professor of clinical medicine. The professor of clinical medicine was interviewed with a professor of the practice of engineering management; together, these faculty members discussed their experience in starting a makerspace housed in the mechanical engineering department as a means to support mechanical engineering course projects. For confidentiality, the universities are labeled A-H, and descriptions of the leaders are kept to a minimum, as shown in Table 8.

Table 8: The corresponding campuses and description of the participants.

University	**Participant**
A	Male engineering faculty member
B	Male engineering faculty member
C	Female engineering faculty member
D	Male engineering faculty member
E	Male lab manager
F	Junior male engineering student
G	Male engineering faculty member*
H	Male engineering faculty member
H	Male medicine/engineering faculty member*

*implied from interview data

The participants represent campuses from East Coast to the Midwest of the United States and have a range of engagement in the space: full participants, overseers of the space, or collaborators towards developing the space.

6.2.3 Interview Design

In a semi-structured interview protocol, interview questions are drafted as a means to guide the conversation. The interviewer aims to have the participants address all of the questions, but this goal is not completed by strictly asking one question after another, as done in a structured interview protocol. The semi-structured interview protocol allows for more of a natural dialogue between the interviewer and the participants. If the participant says something of interest to the interviewer, the interviewer can ask a follow-up question or ask for clarification. In this study, the researchers developed a collection of topics (Figure 20) focused on the formation of an academic makerspace and what the participants' roles were in helping to develop the academic makerspace. From these topics, a series of questions were developed and used to interview nine leaders of eight different university makerspaces. The interviews were conducted in the Fall of 2015. Seven of the eight interviews were conducted using a video teleconference system (Cisco WebEx) while one interview was conducted in person. The interview protocol and design are described below.

Figure 20: Overall themes for interview protocol.

The interviews were focused on obtaining the narratives of how the makerspaces developed and the disposition of each makerspace. With this focus, the participants would have the opportunity to share the struggles and strategies associated with creating, building, and defining the makerspace along with sharing potential insights for others. In order to focus the interviews in this direction, the questions that guided the interview consisted of themes on culture, access, makeup, successful factors, and other aspects. The interview questions that guided the interview covered a wide range of activities (as shown in Appendix I); this chapter focuses specifically on the information that illuminated the origins of makerspaces and the startup process. After all the interviews had been conducted, the interview audio files were then transcribed by an undergraduate researcher over the course of two semesters. This resulted in 104 pages of single-spaced transcriptions.

6.2.4 Makerspace Profiles

For each university where an interview was conducted, a profile was created that was framed by the topics of the interview questions and rooted in the content of the interview data. The profile consists of 1) how the makerspace got started, 2) the current status of the makerspace at the time of the interview, 3) how the makerspace has been funded, 4) how the makerspace works regarding access, and 5) the management model that the makerspace followed. These profiles show the shared experiences of creating a makerspace. The purpose of these profiles is to provide context about the makerspaces and allow others to extract relevant insights for their own creation or expansion of their respective makerspaces. Many questions surrounding makerspace creation or expansion pertain to extracting the experience of what worked and did not work, of how the makerspace received funding, of what the access and management models look like, and how the space started and has expanded. This chapter summarizes that information for the eight various makerspaces.

6.2.5 Interview Analysis

In conjunction with the creation of the profiles, the interview data were analyzed for themes and patterns via multiple cycles of coding. A female graduate researcher and female qualitative researcher engaged in an initial round of coding of the first three interviews, as a means to narrow the focus. Through iterative analyzing and comparing the data, constant comparative analysis (Glaser & Strauss, 1967; Strauss & Corbin, 1990) was also incorporated in the data analysis process, so as to determine any preconceptions and misconceptions that the participants had about making and makerspaces. The two researchers engaged in preliminary analysis of open coding. Through open coding, the researchers dissected and categorized the data, which resulted in fifteen codes. In a secondary analysis, the researchers used axial coding to disaggregate the codes into two core themes: faculty leadership and management & student behaviors and values. After that, the third round of analysis was conducted using selective coding in order to validate the relationship and connections between the two core themes. The preliminary findings of this work were presented in Tomko et al. (2017d) and provided insights from only the three of the eight interviews.

In the second round of coding, the rest of the interviews were analyzed using the open codes. The researchers then used axial coding and selective coding on all of the data in order to assemble four major themes and to validate the relationship and connection between the four major themes. The process and the codes are highlighted in Table 9. Through using multiple phases in the data analysis process, the researchers are able to establish trustworthiness.

Table 9: Overview of codes and coding process.

1. Open Coding	• (Un)planned • Advisor • Barriers • Diversity • Initiative • Need and Goals • Networking • Open • Opportunity • Ownership • Reflection of Leader's Personhood • Resilience • Resourcefulness and Awareness • Safety • Solution • Structure • Value • Workload
2. Axial Coding	• providing solutions in response to students' needs/ideas • being open to diverse users and needs • securing sustainable funding resources • networking with peers • inspiring students to seize opportunity • creating a culture based on student schedules • providing structure to empower students • establishing proper protocols • stimulating personal motivation and initiative to value the space as a co-owner • honoring students' resourcefulness and awareness of needs/ideas
3. Selective Coding	• A NEED allows for A WANT • providing solutions in response to students' needs/ideas • being open to diverse users and needs • ACCESSIBILITY allows for USABILITY • inspiring students to seize opportunity • creating a culture based on student schedules • DIRECTION allows for EMPOWERMENT • providing structure to empower students • establishing proper protocols • ADAPTABILITY allows for SUSTAINABILITY • stimulating personal motivation and initiative to value the space as a co-owner • honoring students' resourcefulness and awareness of needs/ideas

6.3 Makerspace Profiles

The profiles of the makerspaces are presented in a comparison chart (Table 10), which corresponds to a summary of how the makerspace got started. The chart focuses on the ten major categories: type of institution, origin, main drivers, funding sources, location, access, the status of the makerspace, rooms, types of equipment, and management model. Of the institutions that were interviewed, four were technology-based, and four were full-service institutions; further, five were public, and three were private institutions.

The *origin* of the space designates the motivation or need that prompted the designing and building of the makerspace. The *main drivers* focus on the people who ultimately drove the designing and building of the makerspace; this topic is divided into three categories: student-driven, faculty-driven, or donor-driven. The *funding sources* are based on the participants' statements for how the spaces were financially supported. The *location* corresponds to the area on campus that the makerspace is housed in, whereas *access* indicates whether the makerspace is open to the whole campus or not. The *status of the makerspace* captures if the makerspace is still in the works, has recently opened, is still growing into a fully functional space, or is more experienced. Ultimately, all of the makerspaces involved in this study have changed since the time of the interviews. Further, the *rooms* category is meant to demonstrate the layout of the space. Then, the *types of equipment* are equipment that the participant discussed in the interview. Finally, the *management model* points to how the makerspace is run. All of the makerspaces discussed in this study were either using or looking to use a management model that focused on student management of the space.

Table 10: Summary of makerspaces profile information.

	A	B	C	D	E	F	G	H
Type of Institution	technology focused, public institution	full-service, public institution	technology-focused, public institution	technology-focused, private institution	technology-focused, private institution	full-service, public institution	full-service, public institution	full-service, private institution
Origin	Need for space for Capstone	Need for engineering spaces that support curriculum	Need for open space	Need for open community space	Need to grow entrepreneurship program	Need to build a makerspace	Need to occupy new space	Need to incorporate more hands-on culture in the curriculum
Main drivers	student-driven	faculty-driven	donor-driven	student-driven	faculty-driven	student-driven	faculty-driven	faculty-driven
Funding Sources	University fee money Corporate sponsors	State Funding – building renovation State Funding – equipment trust fund Departmental purchases College funding	University funding Alumni donors *anticipated corporate sponsors	Donations	Donations	I-Corps grant Launch-pad incubation College of Engineering College of Business Venture capital group State government *Potential corporate sponsors	Private funds Membership dues	Department funding University funding
Location	housed in the mechanical engineering department	housed in the engineering department	housed in the basement of the Union building	housed in the mechanical engineering department	housed on the research floor in the biomedical and chemical engineering building	housed in the business incubator, next to the college of engineering	housed in the new area of campus	housed in the mechanical engineering department

Table 10 Continued.

Access	open to the whole campus	limited to engineering	open to the whole campus	open to the whole campus	open to the whole campus	open to the whole campus	open to campus and community	open to the whole campus
Status of Makerspace	experienced, but still growing	in the works	in the works	recently online	growing	growing	in the works	growing
Rooms	Six rooms	Three rooms in the basement	One large room in the basement	One room	One room	One room	Part of the campus (17000 sq. ft. planned)	One 15 by 15-foot space
Types of equipment	3D printers, laser cutters, anodizing equipment, fume hood, drills, woodworking machinery (bandsaw, miter saw).	3D printers, laser cutters, mill, lathes, CNC machines, computers for CAD, a projection system	3D printers, laser cutters, mill, electronic equipment, craft supplies	hand tools, laser cutters, 3D printers, laser cutters, mill, lathe, routers, waterjets	3D printers, laser cutter, hand tools, band saw, drills, CNC	3D printers, mini-mill CNC, whiteboards	3D printers, laser cutters, woodworking, electronics	3D printers, hand tools, hand power tools
Management Model	Student volunteers run makerspace under the oversight of two faculty members	Lab manager and student workers manage the space	Mostly staffed by students with university staff oversight	Student-run makerspace with faculty oversight	Lab manager and student workers manage the space	Staffed by students. The only full-time student reports to around six faculty/staff.	Specific staff members hired to supervise space; talk of using a member involvement model (similar to GT)	Student volunteers run makerspace under the oversight of faculty members

6.3.1 University A – Georgia Tech Model

The first profile presents the details on a makerspace housed in the mechanical engineering department of a public, technology-based institution. This makerspace began out of a need to provide space for the Capstone design course, where students would be able to prototype and store their projects. A faculty member took responsibility for negotiating space, machinery, and funds for the Capstone design course. The makerspace emerged from a mailroom that was being underutilized, the machinery came from a machine shop that was going out of business, and funds were secured from numerous sources: excess money from a sophomore design course, corporate sponsors, and university fee money.

Due to the need to ensure safety and lack of funds for a Teaching Assistant to monitor the space and machinery, the faculty member sought out volunteers from instructors and then from Capstone students who had experience using a machine shop. This resulted in a management model where the students would lead and run the space, under the oversight of two faculty members, in exchange for 24/7 swipe access. Eventually, more than just Capstone students started using the space, and the makerspace opened for the whole campus to be able to use. In turn, the makerspace grew to have officers, student volunteers training others and supervising equipment, and students taking ownership of the space by working on both personal and class-based projects.

6.3.2 University B

The second profile presents the details on a makerspace housed in the engineering department of a public, full-service institution. At the time of the interview, the engineering department was working on setting up and designing the maker area for the engineering program, looking towards what other makerspaces (like Georgia Tech). The spaces would support the curriculum, research, independent studies, design projects, faculty-driven student projects, student-driven interfacing faculty projects, and classroom projects. Because the engineering program was in start-up and the building was being renovated, the endeavor was being supported through equipment trust funds, departmental funds, college funding, and state funding.

During the process, a faculty member took over a large storage space and turned that over into a design visualization space with 3D printers and laser cutters, helped transition the machine shop into a larger space with proper protocols for rules and access, and aided in setting up the fabrication space that students would use in their courses. While initial usage was low, after offering a class and training, there became a steady stream of student engagement. To maintain engagement, this led to an access model where students are trained and hired by a lab manager to be in the facilities when the facilities were open.

6.3.3 University C

The third profile presents the details of a makerspace housed in the basement of the union building of a public, technology-based institution. While the university had shop spaces and project spaces, these spaces were limited to students meeting specific criteria, including major-specific, class-based, or club-based spaces. The university was in need of an open, inviting environment with fewer restrictions on access. Having to upgrade the bowling alley in the basement of the Union, the president of the university followed the recommendation of donors and asserted that it would be a good space for a makerspace.

At the time of the interview, the makerspace was in the process of being recommissioned. The director of the Enterprise program – a program where students work in teams to create innovative solutions for a client's project – was working as the focal point for developing the space and getting students involved. One of the core student groups, the University Innovation Fellows (UIF) was providing input, drafted the list of equipment for the makerspace (using Georgia Tech's website), and were the main drivers for designing and engaging the space.

6.3.4 University D

The fourth profile presents details on a makerspace housed in the mechanical engineering department of a private, technology-based institution. The movement toward a student-run makerspace was a combination of students finding areas on campus where they could build and the departments beginning to understand the value of a makerspace. Initially, there were numerous spaces on campus dedicated to designing and building, but these spaces were for classes and research. After a visit to Georgia Tech's student-run makerspace, a faculty member helped to advocate for a similar type of makerspace housed in the mechanical engineering department.

While this faculty member supervised the designing of the space, it was the graduate students who took to running the facility. If someone were to want access to the makerspace, they would attend an hour and a half long meeting where they would get basic shop training, safety training, and hand tool training. Then, if a student wanted access to more complicated equipment (e.g., laser cutters, 3D printers, mills, lathes, waterjets, routers), then individualized training would be provided by the graduate students. At the time of the interview, the makerspace had been online for a semester, and the graduate students had trained between 400 to 500 students, whereas the other university spaces would typically have trained 300 students per year.

6.3.5 University E

The fifth profile presents details on a makerspace housed on a research floor in a building shared with biomedical and chemical engineering. The makerspace emerged from the university's desire to grow its entrepreneurship program. The university outfitted a 600 square-foot room in the biomedical and chemical engineering building with one 3D printer, one laser cutter, hand tools, a small band saw, and a small drill. Initially, students were using the space but did not have much motivation. Eventually, students with more of a maker culture mentality started occupying the space 24/7. It was these students who took it upon themselves to use the space and make things.

However, the students needed greater supervision, more resources, and a better-outfitted space. After a meeting with the president, a donor offered to fund the space given that the equipment was not a replication of what was already available on the campus. The students looked to outfitting the space with multi-use tools and knockoff brands, such as the Flash Forge 3D printer. In efforts to create a culture around making and not become a service bureau, a lab manager and two paid students would run the space and support both personal and class-based projects.

6.3.6 University F

The sixth profile presents details on a student-led makerspace that was open to the whole campus yet located in the business incubator and near the engineering building. The beginning of the makerspace for this university was a combination of a National Science Foundation (NSF) grant and a student initiative. The university had a National Science Foundation grant through Innovation-Core to start a makerspace on campus. A year after receiving the grant, a sophomore student approached their academic advisor about wanting to start a makerspace at the university in conjunction with a maker student organization.

The sophomore student started a non-profit maker organization on campus and managed the evolution of the makerspace. The makerspace was designed to focus on digital manufacturing so as to expose students to hands-on experiences with newer technologies. The makerspace was open to anyone who would go through orientation and training. At the time of the interview, there were priority groups (students who have priority in using the machines); these groups included: classes where students would be building a prototype of some sort (e.g., senior design), Launchpad incubation clients (people who have start-ups in the business incubator), I-Corps, and Maker Society.

6.3.7 University G

The seventh profile presents details of a makerspace open to the campus and community. The state fairgrounds were initially adjacent to the campus, but the state decided to move the fairgrounds to another location. In turn, the university obtained the space and decided to build a makerspace there. At the time of the interview, private funds were being raised, and the university had built out about a third of the space. Additional funds were generated by membership fees. Since the makerspace was open to students and the community, the cost for membership ranged from fifteen to fifty-five dollars a month depending on whether a person was an undergraduate student, graduate student, faculty, alumni, or unaffiliated.

The aim was to produce an innovative makerspace. The university hired a director for the initiative: a female artist. She had a massive role in the design of the space, which included an art studio, a digital fab lab, an electronic facility, a wood shop, a dark room, a mold making room, and then a gallery space. The overall model was still emerging, and the university was looking to adapt their staffing model to follow a Georgia Tech model, due to the energy and diversity of a member involvement model.

6.3.8 University H

The final profile presents details of a makerspace that is open to the campus and housed in the mechanical engineering department. There was a former mechanical engineering classroom that was slotted to teach smaller classes, but the makerspace was not a suitable classroom due to it being a glass-walled space. Two professors negotiated using the space for a makerspace. Using their own personal funds and departmental funds, the professors were able to outfit the space with some 3D printers and hand tools. While the intention was for the space to be open to everyone, it started with mechanical engineering, electrical engineering, biomedical engineering, and computer science benefiting at first, and then it became a school of engineering initiative.

The professors structured the space to support mechanical engineering course projects. Eventually, the makerspace expanded into other majors, but this evolution was mostly from individual student interest, and then these students would use the space for both personal and class-based projects. Maintaining this type of space led the professors to Georgia Tech's staffing model. The makerspace became managed by student mentors, starting at eight students and evolved into 45 student volunteers, at the time of the interviews. Similar to Georgia Tech, these students volunteered time in the space in exchange for 24/7 swipe access; however, hours were adjusted to be 2-11PM open hours on weekdays.

6.4 Findings for Best Practices

During the data analysis process, four major themes emerged regarding common practices associated with university makerspaces (see Figure X). The first suggests that a need allows for a want, where designing a makerspace to fulfill a specific need results in students coming to the makerspace and wanting to use the space for identified projects. Second, accessibility allows for usability. The more accessible the makerspace is for students, the more use the makerspace will get. Further, direction allows for empowerment. A space that has some form of structure and protocols will allow students to thrive because the students are able to understand the boundaries and opportunities found there. Finally, adaptability allows for sustainability. The rules, guidelines, and protocols associated with the beginning of a makerspace may not work as the makerspace grows.

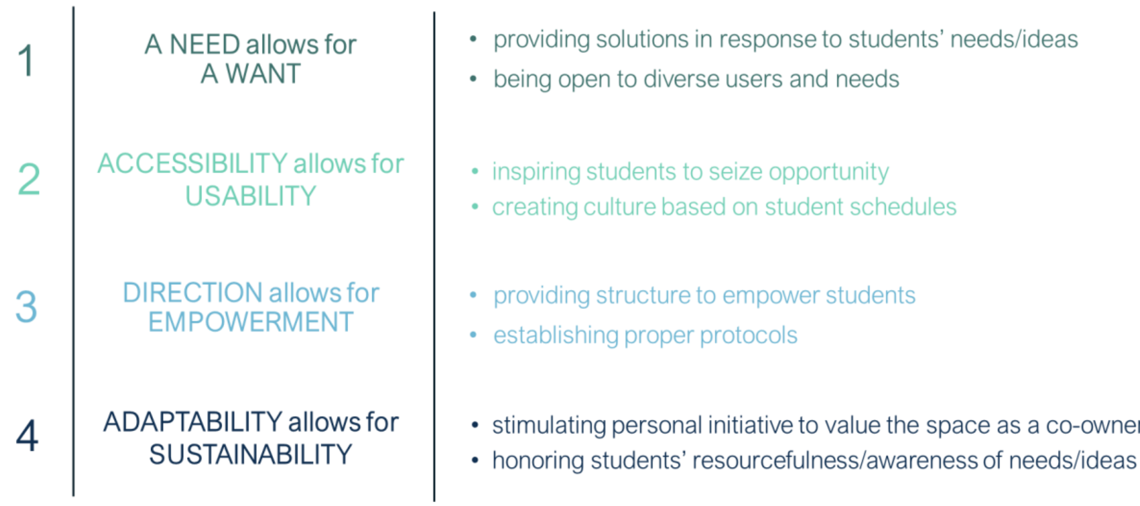

Figure 21: Themes for best practices.

6.4.1 A NEED allows for A WANT

The participants share both implicitly and explicitly that a makerspace grows from catering to a specific need. To do so, attention should be given to provide solutions in response to students' needs/ideas and also to be open to diverse users and needs. For one university, the need came from providing space for Capstone students. "Capstone had previously had a space, but [a sophomore engineering design course] had kind of absorbed it so there was actually no space for Capstone at that time. So I think that was part of the deal to that ok Capstone needs a space." The makerspace eventually develops as the emerging needs are addressed. The participant addresses that this makerspace needs to be able to address a critical demand: "Like if you just say like 'Hey 3D printers have fun' it's not a clear cut need. There has to be a group that is desperate for this stuff already."

No matter the interest or excitement around the technology in a makerspace, eliciting and exploiting a particular need will encourage students to use the space. An example of this is shown in another university, where a makerspace was created, but students were not using it. In turn, a faculty member *created a need* for the makerspace. This need was not forced via a required course, but instead remained an optional elective for students as an elective class.

> The first space we put together here had six 3D printers in it and one scanner, and it had a projection system, and it sat fallow for seven months. Students could use it; training was available for the students to use it. We had a TA in the space. People weren't using it. And so I decided to offer a class when we got another 3D printer, and I might be miscounting the number we began with, too hard to remember. And I offered a class in the space, trained all the students to use it. The class interfaced the students with 3D printers, interfaced the students with the CNC, interfaced them with soldering, showed them how all this comes together to prototype, make and do things, work with all the different equipment in the building. And in the following semester or two, there was a steady stream of students in and out of that space.

This example demonstrates that even though there was not an original need for the makerspace, a need could be created. In this circumstance, the need was elective, and the students had a choice in taking the elective class. Some questions around makerspaces relate to whether or not students should be forced into the makerspace for a course. Individual members of the maker community may argue that a makerspace is meant to be open and for unstructured use. Ultimately, there is not a single answer to this question. Previous work on makerspaces has identified that students with no previous makerspace involvement are more likely to become involved if given a class assignment (Hilton et al., 2018c). Additionally, while the university described in the example above created an elective need for the makerspace, the university was also developing a curriculum centered around making activities; in this case, the need would then require students to use the makerspace for course-related endeavors. Therefore, in order to launch a makerspace, there has to be a relevant need, whether that is for personal, research, extracurricular, or course-related endeavors.

6.4.2 ACCESSIBILITY allows for USABILITY

While the participants discussed shops and project spaces for students to make things on campus, there were usually tight restrictions on the spaces, such as being only for research or for a specific group on campus. Of all the profiles, only one was limited to engineering because the campus already had makerspaces and because of concerns regarding throughput for such a small physical space. For one university, the current model at the campus discouraged students from using spaces in buildings that were not of their home major: “I think students probably have the impression that they would be discouraged or wouldn’t be able to do it. Which is true they would be discouraged.” This restricted access blurs the lines of what is and what is not accessible – ultimately squashing the opportunity for students to use the space.

Creating an accessible space requires that students be inspired to seize opportunity and that the culture is created based on student schedules. For University H, the makerspace hours of operation were heavily influenced by student schedules, even despite pushback from faculty.

> …. we wanted the space to operate on student hours not faculty hours. You know the students don’t work at 9 in the morning on these kind of projects. You know so it would have been kind of useless to them at that time. There has been pushback from the faculty that, ‘I’ve walked by at 7:30 [am] every day and there’s no one in there.’ And I’m like yeah there’s no students anywhere except sleeping.

By creating a space centered around students’ schedules, the makerspace becomes more accessible. Even though the participant jokes that students are sleeping at 7:30 AM, this is a realistic consideration for academic makerspaces at a higher education institution. On a similar vein, student-run spaces or makerspaces where students are given opportunity, this provides them with more access to acquiring new skills and supplements their ability to use the space. For another university that already focused on designing and building in their curriculum, the participant echoed the benefits of having a space that was specifically student-led, which was a relatively new concept to this particular university. In creating a makerspace that allows students to take on new opportunities, it also generated a change in the student's attitude and ultimately, the culture of the space.

> And I see this helps in two ways. The students that run that space, their learning a lot about management and mentorship, it's helping a lot of them decide whether or not they want to have education as a career. And then the students that use the space, the primary benefit, the primary impact for them, is that now they don't have any restrictions, right, on what they want to do, so there's an attitude change, right, a moral change amongst the students.

Because of the type of access to the makerspace, there were fewer barriers to accessing the space and more opportunities to use the space. The usability of the space became more than just the tools; now, the students were learning how to manage and how to mentor in the space.

Alternatively, the physical access to the makerspace impacts the usability of the space, concerning visibility, signage, barriers to entry, or hours of operation. One university organized the makerspace such that "the timing is driven by the hours the [student workers] can work or the hours they can consistently go to a quote shift." Therefore, instead of the typical 8AM-5PM hours of operation, the makerspace was open from 2-11PM and on Sunday evenings Ultimately, when a makerspace becomes more accessible to the students, "students are more likely to use it because the barriers that they perceive are lower."

6.4.3 DIRECTION allows for EMPOWERMENT

Through providing structure and establishing proper protocols for a makerspace, the students become empowered in their use of the makerspace. The clarity, guidelines, support, rules, and structure associated with the makerspace allow students to understand and profit from the opportunities in the space. As such, they have direction, whether they are helping to run the space or only a user in the space. The direction fosters the students to be able to grow in their skills and abilities. This can even be seen in the classroom. Providing the students with a clear direction for solving a problem helps them to be able to solve it on their own, which thereby empowers them in their abilities.

For one university, the participant talked about the different roles in the space, such as the executive board and the mentors. Afterward, the participant addressed the benefit of having regularly organized meetings with the mentors so that the mentors could voice their concerns and insights about the makerspace. During one of the meetings, it emerged that the students wanted to have “a bicycle repair stand. Subtle, simple, hundred plus dollar item it's nothing amazing, but it really, really enhanced for the people working on their bicycles that experience and the ability for them to plug away and work on their bicycle.” Through actively listening and responding to the students’ concerns, the participant shows support and encouragement for the students’ efforts.

Nevertheless, it is not always an easy and simple experience. One university was in “a struggle to be honest. I mean, we're still trying to define ourselves. We didn't want to come down and say, ‘This is only for personal projects,’ because we like to support the multi-disciplinary projects and this will get industrial design and engineering work together.” Clearly identifying what the role of the space will be remains a challenge. To the point that even faculty who are not engaged in the space can misunderstand the purpose. “Faculty members are using it, but they don't necessarily know what's in there … we've had several faculty that wanted to have a class come down there and basically courting off the studio … So there's been a little bit of a misunderstanding I think from faculty that it is a student-driven space, and that's a fight that the faculty don't steamroll over the students.” Driving change through integrating a makerspace at a university indicates that confusion is bound to occur. “So there’s discussion of when we set up the spaces, setting them up in such a way that changes the access protocol.” While navigating the purpose of the makerspace, it remains crucial to set-up proper protocols. Protocols that answer questions of: what is the purpose of the space, how does one access the space, who can use the space, etc. Setting up these protocols at the fore-front can help to limit the confusion later on.

In conjunction, it is also important to identify the differentiating factor of the makerspace. If the makerspace is the only one on campus or if there are numerous makerspaces on campus, then what is unique to the one's makerspace? For example, "one of the things that we're doing differently than many spaces is we're really pushing for that diversity of membership." By identifying the differentiating factor, then this contributes to the direction of the space and how the people in the space feel empowered by the space.

6.4.4 ADAPTABILITY allows for SUSTAINABILITY

When a makerspace starts, certain factors are implemented in order to get people using the space. However, once students and faculty become more excited about the space, the models used to maintain the space need to be adapted for the space to be sustained. One university stated that starting small was beneficial but then started looking to the Georgia Tech model for something more sustainable. Further, one participant stated that "We just discovered along the way what worked and what hasn't worked. So that's what I encourage schools to try to do." Ultimately, the participants' discussions on their respective makerspace showcased that stimulating personal motivation and initiative for students to value the space as a co-owner and also to honor students' resourcefulness and awareness of needs/ideas were ways to promote adaptability.

For one university that was still constructing the makerspace, there was a "student group has kind of taken leadership in what that will look like." While there was not a set plan, the university was being adaptable to the uncertainty of the space and also letting the students take the lead. Throughout the interview, there was uncertainty in how the makerspace was going to develop. However, the participant talked of “figuring it out” as they went along and that what would work in the beginning may not work later on.

For another university, the students needed a more accommodating space; while a donor would supply funds for the students’ endeavor, there were limitations. In efforts to maximize the output, the students adapted and sought out tools that would have multiple uses and were of lower costs.

> We went with the knockoffs of maker bot, the flash forge which are a third of the price. So, our buying capacity went up, so I was able to purchase five of those for the price of two Maker bots, and our uptime has been great. We've had over 1800 print hours per printer, 1500 prints total in just 16 months.

Through working within a provided scope, the students and the lab manager determined more effective ways to outfit the space such that the space that could function long-term. While this included getting knock-off brands and multi-use tools in order to adapt to the culture and the budget, the makerspace was able to support more students for a more extended period of time.

6.5 Discussion

Through a semi-structured interview protocol, nine leaders of eight various makerspaces nationwide discussed their experiences of creating and starting a makerspace at their respective universities. The interviews sought to gain a variety of perspectives via examining makerspaces that were in different stages of progress. At the time of the interviews (Fall 2015), academic makerspaces were a newer concept - the idea of a space dedicated for students to work on personal projects and a space that fostered a maker culture. From the interviews, most participants discussed a period where they looked at other models for running a makerspace, particularly the Georgia Tech model. The leaders of these makerspaces wanted to have a space that students desired to use, that students actually used, that students would feel empowered to use, and that students would always use. Especially since these spaces are not an inexpensive endeavor, leaders wanted to have a certainty that the makerspace would be worth the investment. These interviews showed that designing an engaging makerspace requires that a need is associated with the makerspace, that the makerspace be accessible to students, that there be clear direction and support within the space, and that the makerspace is adaptable to accommodate for the changing needs and desires of those invested in the space.

Furthermore, what works in one space is not a guarantee to work in another space. The participants were aware of this factor. When examining other makerspaces, the leaders would point out that cultural differences between universities must be considered. "We’ve definitely had things that failed here, but you know they may work somewhere else for a different environment; a different, you know set of circumstances.” In all of the leaders’ experiences, there was some form of failure. In order to overcome the failure, the leaders talked about adapting to the failure and utilizing student input in order to navigate an approachable and appropriate solution.

Additionally, makerspaces coming online or desiring to make improvements have numerous questions regarding funding, management models, access models, etc. In order to address these types of questions and concerns, this chapter presented a comparison chart is provided for the different makerspaces that were involved in this interviewing process;

this summary includes: type of institution, origin, main drivers, funding sources, location, access, status of makerspace, rooms, types of equipment, and management model. This chart is accompanied by a summary that described the experience associated with starting each makerspace. The juxtaposition of the chart and the summary provides context for the reader so as to help ensure a more thorough understanding of the experiences associated with starting a makerspace.

6.6 Limitations and Future Work

There are a few limitations to consider for the study presented in this study. First, the dataset of this study focuses on leaders of various U.S. university makerspaces. We did not extend our interviews to international makerspaces. As such, differences may exist in how the findings can be transferred to international makerspace environments, which is an area of future study.

Additionally, there were a few minor limitations in the methodology. First, the person who conducted the interviews was not the same individual who conducted the analysis. The person who conducted the interviews graduated in the middle of the project, leaving analysis for another individual. Another limitation of the study was that the data is self-reported, where interviewees varied in the level of detail that they were able and/or willing to provide regarding the various interview topics. While a semi-structured interview protocol was appropriate, hindsight shows that a tighter protocol might have produced consistency in the level of detail between interviews. Another limitation of the study is that most of the interviews were conducted over an online video system. While this procedure allowed for more interviews to be conducted, an interview in-person would allow for a more engaged and dynamic dataset.

Further, this study focused primarily on the faculty/staff of the universities, which results in mostly male participants. The perspective of students is not highlighted in this study, because that was not the intent. The former chapters of this dissertation aim to gain insights from student users. Whereas, the intent of this chapter was to provide the backend origins, insights, and understandings from leaders. Findings from this study are transferrable to other makerspaces worldwide, but must be taken understanding the context of these interviews.

6.7 Conclusions

Creating a makerspace has a variety of challenges. While any person seeking to start or improve a makerspace wants to ensure success, the success of the makerspace is accompanied by failures, and there is not a single solution. However, there are certain practices that are common in the experiences of makerspace leaders: a need allows for a want, accessibility allows for usability, direction allows for empowerment, and adaptability allows for sustainability. Through designing a makerspace with these specified practices in mind, a makerspace has the opportunity to support and engage students. It is important to note that these findings emerged from makerspaces at various universities that were all seeking to foster student engagement, most likely through students having an active leadership role in the space. Still, the universities all adapted this type of model to fit the culture of their respective campuses.

CHAPTER 7. CONCLUSIONS

7.1 Qualitative Inquiry in Engineering Design

Engineering design is ever changing as technologies, processes, systems, users, teams, and conditions continue to evolve and adapt to each other. The very dynamic and intricate nature of engineering design invites methodologies that can match and provide valuable insights toward interactive and complex phenomena. Yet, engineering design research remains heavily dominated by quantitative methodologies, as demonstrated by the literature in the Journal of Engineering Design (JED) and the Journal of Mechanical Design (JMD), where the use of qualitative research methods are limited or ambiguous. For instance, a quick search for “qualitative research” respectively yields zero results and seven results (Eng et al., 2017; Fu et al., 2014; Hey et al., 2007; Lauff et al., 2018; Meluso & Austin-Breneman, 2018; Reap & Bras, 2014; Schaffhausen & Kowalewski, 2015); these seven studies limit the emphasis and details of the qualitative work so as to suit the audience and the nature of the journal. Moreover, a simple search for “qualitative” work results in studies where activities are labeled as ‘qualitative’ but are not referring to qualitative research methods. For example, Andersson (1997) used a “qualitative approach,” which entailed describing how certain design principles contribute to the robustness of a system. In a similar vein, Angeles (2004) describes a topology for parallel manipulators used in robots by implementing “qualitative reasoning” and a “qualitative analysis” is used to present the trajectory-portraits of a simplified second order differential equation (Sorge, 1996) – both papers are heavily populated with equations. Also populated with equations was the paper that describes a new sequential sampling method that uses both quantitative and qualitative information from different sources (Rai & Campbell, 2008). While clearly these papers are rigorous and are using a qualitative technique in their study, these studies are not utilizing qualitative research methodologies, and it is these types of papers that permeate JED and JMD as having a qualitative influence.

Not having qualitative research methodologies appropriately represented in engineering design research journals continues to perpetuate the cycle and diminish the potential for truly engaging engineering design research through qualitative studies. When used in its' full integrity, qualitative research offers numerous opportunities for a better understanding of engineering design and enhancing engineering design research. Because qualitative research highlights context as a critical feature of the methodology (Borrego et al., 2009; Van Note Chism et al., 2008), this allows a detailed understanding of the circumstances in which a phenomenon occurs. Further, findings are presented in some form of a thick description (Geertz, 1973), which allows the transferability of knowledge (Hoepfl, 1997). Transferable findings allow readers to extract findings from one study that can be matched against findings to similar communities or research sites, leading to transferability across research sites.

Recognizing the strengths and advantages of using qualitative research methods in engineering design, certain engineering design researchers have accessed the potential of qualitative research and forwarded the conversation by demonstrating the value of using qualitative research in engineering design studies (Adams et al., 2009; Adams et al., 2011; Ahmed et al., 2003; Bucciarelli, 1988; Cross & Cross, 1998; Daly et al., 2013; Daly et al., 2012a; Zoltowski et al., 2012). In one particular argument, Daly et al. (2013) asserts the opportunities of qualitative research methods, specific to engineering design, and then proceeds to present a case example that triangulates surveys, semi-structured interviews, and ethnographic observations as a means to study large-scale complex engineered systems. She argues, "Qualitative research done properly is as rigorous as positivist approaches of quantitative studies" (p. 3). Consequently, one of the largest challenges with qualitative research in engineering design is the seemingly irreconcilable positivist approach to research espoused in the community, causing numerous qualitative research methodologies to remain untouched despite the potential of these alternative approaches to generating rich and transformative insights for engineering design.

7.2 Contribution 1: A Methodological Roadmap

Qualitative inquiry offers an opportunity to gain deep insights into the complex phenomenon associated with engineering design. As engineering design continues to evolve, it becomes essential to determine means that appropriately evaluate and engage phenomena of interest. In this work, we described a phenomenologically based interview process and how this process was adapted for the engineering design audience. The data generated from this methodology was further enriched by the ability to adapt the interview protocol to cater to the participants and interviewer. The adaptations made to the interviews (such as having individuals create timelines and bringing prototypes) added tactile and tangible references, allowing for a discussion piece in the interview. Moreover, the verbal timeline that participants provided in the first interview was validated and endorsed by the timeline that they draw in the third interview. Regardless, the participants' willingness to openly share their stories is rooted in the mutual respect between the interviewer and the participant. It is important for other researchers, who are considering qualitative methods, to seriously evaluate and articulate how mutual respect will be attained. Otherwise, this methodology is not guaranteed to provide valuable insights. Another important consideration is that developing the appropriate research questions and interviewing protocol requires a great deal of time. In this research, two years were spent simply in exploration, and an additional year was spent in developing the appropriate protocol. The in-depth interviewing process is not suggested to be used for a study that aims to explore a field. This is because the presented methodology is targeted at delving deeper into certain phenomenon

Through describing and presenting the methodology in a specific context, we demonstrated how a phenomenologically based interviewing process and grounded theory data analysis methods can capture the lived experiences and the meaning of these experiences through emerging codes, an emerging typology, and emerging themes. Strikingly, investigating the lived experiences of women students through qualitative inquiry illuminated both the breadth and depth of the forms of learning that they are engaging in. The breadth and depth of the typology would not have been attainable through even a small number of controlled design studies, surveys, or quasi-experimental designs. Qualitative inquiry produces an extremely rich dataset for highly uncontrolled and unstructured environments; such environments are extremely difficult to study using other approaches that demand initial detailed information on what is being learned and how learning is occurring.

Tapping into the advantages of the presented methodology, other current research endeavors could benefit from expanding their work to include the phenomenologically based interviewing process. For example, this methodology can be used to obtain expert knowledge at a deeper level than is typically engaged by the Delphi method. Also, the interviewing process would assist in understanding how a team or company's design process has evolved over time, along with gaining insights into why the design process has changed and why individuals believe the process to be effective. Further, a designer's past experiences in testing prototypes impact their current decision; this methodology would excavate what the impact is of past experiences on current design decisions. Moreover, the grounded theory approach is particularly useful when there is limited existing knowledge, research, or theory on a present engineering design phenomenon. Ultimately, this methodology, when used as a means to produce a typology, can be used for extracting any form of typology: types of design projects, types of prototypes, types of problem interpretation strategies, types of analogies, types of student engagement, types of function decompositions, types of empathy, types of creativity, or types of barriers to engineering design. Since engineering design is informed by experiences, this methodology allows for extracting the insights from all types of experiences, whether that be Capstone students, students in a first-year design class, K-12 students, industry, faculty, administration, etc. All people engage in experience; engineering design researchers simply have to determine what experiences will help them further understand a particular phenomenon. For many current research endeavors, the phenomenologically based interviewing approach would allow for rich datasets and insights into the phenomenon of interest.

7.3 Contribution 2: Learning in Makerspaces

Moreover, in Study One and Study Two, we examined how makerspaces support learning for women students by examining what different types of competencies and learning are unfolding. The purpose of this research endeavor was to first develop out a typology of learning as a means to ultimately create a learning model that represents the interaction between competencies (showing how design learning unfolds). As such, we implemented the three-series in-depth phenomenologically based interview methodology with five women students and then the targeted, single interview protocol with fifteen women students. The first set of interviews were analyzed using grounded theory techniques as a means to develop a typology of learning. Upon establishing inter-coder reliability on the typology of learning, we further used the typology to code both sets of interviews. From this analysis, the patterns and themes that emerged were discussed in order to forward the generation of a learning model. This learning model showcases the relationship between cognitive, intrapersonal, and interpersonal competencies.

As such, we crafted and validated a typology of learning, extracted themes of learning from women student narratives, and developed a learning model. Collectively, the typology, themes, and model demonstrate the intricacy of learning harnessed in a university makerspace. The typology demonstrates that makerspaces offer exposure and procurement of a wide-ranging skillset, where women students are learning:

- how to fail
- how to struggle
- how to practice
- how to iterate
- how to explore
- how to communicate
- how to manage
- how to observe and listen
- how to collaborate and work with others

- how to receive and solicit help
- how to give help or instruction
- how to lead or administer
- about design
- about manufacturing and tools
- about computational tools
- about materials
- about access conventions and protocols
- about rules of the community
- about gendered associations
- how to improvise
- how to seek opportunities
- how to be resourceful
- about confidence
- about patience
- about resilience
- about reflection

With the breadth of types of learning and competencies, we are able to further engage the themes and understand what type of environment a makerspace is.

- "environment where everyone is learning" = learning environment
- "design journey" = design environment
- "laboratory for creativity" = open, creative environment

Then, given the typology and the themes, the learning model exposes the dynamic nature of the makerspace, where the types of learning and competencies are intertwined and impacted by each other. The more an individual negotiates and navigates the culture, then the more opportunities that they have to engage in the makerspace, make more projects, and learn various equipment/tools. The learning model alone showcases the power of culture in promoting academic learning, and that both intrapersonal and interpersonal competencies, while small in comparison to cognitive competencies, support and influence the individual's overall opportunity to learn and engage in the makerspace. Together, these learning findings promote the following:

Makerspaces are open, dynamic, learning design environments, where collaboration, support, failure, and resources invite a breadth of skills/competencies and open the doors to creativity, inspiration, and confidence.

Alternatively, the learning findings produced in this dissertation provide immeasurable insights and opportunities for other makerspaces. The typology of learning provides a structured articulation of what is being learning in the makerspace, while the learning model demonstrates how learning occurs in the makerspace. Other makerspaces and/or researchers can use the typology and model as a means to analyze or assess the learning of their own makerspaces. Here, we have set the foundational work for the overall learning engaged in a makerspace. Further work can look to dive deeper into certain categories (e.g., looking at the design competencies in more depth), to examine other types of makerspaces (e.g., industry, community-based, etc.), or to examine other demographics (e.g., men, transgender, underrepresented minorities, etc.). Given the work presented in this dissertation, the findings are transferrable and applicable to other makerspaces and potentially other community-oriented spaces (provided that the content knowledge and skills of the typology might change for a specific community). Ultimately, it is important to understand that makerspaces afford a diverse learning typology, and the acquisition of a diverse skillset comes from the opportunities provided within a makerspace. Makerspaces are not only made by the equipment/tools and space alone but also the culture.

7.4 Contribution 3: Pathways into Makerspaces

Corresponding to the second research question, we sought to understand the pathways of women students into and through a makerspace. While participation in outside communities is seen as a strategic pathway for engaging students in academic endeavors (Allendoerfer et al., 2012), it is important to note that around the world girls and women makers come to making via multiple pathways (Intel & HarrisPoll, 2014). Still, from an engineering education standpoint, there is little known about women student pathways into an academic makerspace, where there are nuances of a makerspace rooted in an educational system. To extract these nuances and pathways requires using means appropriate for capturing women student narrative and lived experiences, as found in qualitative research methods. Adding to the conversation, we sought to understand pathways through a making ecosystem as women become members of the academic makerspace COP. Where Lord et al. (2019) suggests that an ecosystem framework offers the ability to explore contextual factors for understanding phenomenon in engineering education, there is potential to understand student pathways through a making ecosystem and into an academic makerspace COP. In that, the ecosystem can capture student's previous experiences, which are heavily influenced by a variety of factors such as exposure to making, socioeconomic status, among others. We implemented a research study in efforts to understand the contextualized, influential factors and barriers that impact women students' design and learning pathways into and through an academic makerspace. Using a phenomenologically based interviewing process, we recruited women students to participate in an in-depth reflexive conversation about how they came to be involved in the makerspace and what their experiences were. Then, using grounded theory analysis techniques and the constructs of communities of practices, we extract themes for understanding women students' pathways into an academic makerspace. These themes showed pathways as "my background of making," "formative in my journey as a maker," and "being a woman maker." Expounding on the themes, we further developed a model for showing pathways into the makerspace through a making ecosystem.

From the data and findings, it remains clear that the women student pathways engage various factors and that no single path defines their journeys. Nevertheless, there are numerous influential factors and barriers collectively characterizing women student pathways. For example, more support and encouragement are needed for women as they navigate into makerspaces and making experiences. In particular, the positive and encouraging experiences in a woman's youth are crucial towards motivating them to engage in a makerspace later on. These types of experiences start with the family and their home environment, which are further nurtured by school (both in the classroom and in extracurricular activities), work, or personal activities. It is in K-12 initiatives where young girls and women can be exposed to the value of engineering, design, and making, which leads to them engaging their own potential and ability to do engineering design.

Moreover, gendered barriers continue to exist for women students. Most women have some form of arts & crafts integrated in their background. To most effectively achieve inclusivity for women students, these types of activities should be at the forefront of a makerspace. Staff of a makerspace should be instructed in how to cultivate a culture of inclusivity, to not only help women to feel welcome but also to invite and allow for a culture where men are not seen as less ‘manly’ when using equipment that has traditionally been associated with women (e.g., sewing machine, vinyl cutter, etc.). The inherent disposition that women are not makers and are foreign creatures to a makerspace needs to stop both in their youth and in their college experiences. Women are still laughed at or given positions that do not allow for engaging with the hands-on parts of projects. Women are still fighting for their place in engineering and design. To change this narrative, the makerspace needs to show women that they are welcome by refocusing the culture to allow women to be themselves and to be centered on the community’s passion for making.

Furthermore, pathways into the university makerspace needs to allow for variety. Accessibility is more than just an unlocked space with tools; it requires intentionality and diversity in exposing the space to students. When women students come to the university, recurring exposure to the space, whether through class or extracurricular activities, will provide a need for the women to use the space and also the most opportunity for them to become engaged in the space. This opportunity is further expanded when makerspaces offer various ways to engage in the space, such as a user, an executive member, a project lead, etc. Ultimately, the goal for bringing women students into the space is to decrease barriers to entry. For instance, to making it easier for women students to know how to use a space, we suggest establishing a coherent and easy-to-navigate online presence, having recognizable signage, and providing direction through workshops, tutorials, example projects/instructions for how to make example projects, or instructions for how to work machines. In order to change the narrative that women are a part of design, makerspaces must unmistakably exhibit that women are already a part of design.

7.5 Contribution 4: Best Practices for Makerspaces

Lastly, while the makerspace provides access to both thought and equipment (Halverson & Sheridan, 2014; Pernia-Espinoza et al., 2017), it is believed that this type of open environment is the next generation classroom (Colegrove, 2016). When considering the transition towards an educational system that focuses on making activities and makerspaces, numerous concerns and questions arise about funding sources, access plans, management models, and potential culture. Ultimately all with the underlying questions of, "is the risk worth the reward," and "what can we do in order to make our makerspace successful."

In response to these questions, researchers began investigating the successful factors associated with university makerspaces (seemingly engineering-based makerspaces). In a study of seven successful makerspaces, Wilczynski (2015) articulated that a successful makerspace is associated with a clear mission, proper staffing, open environment, maker mindset, and access to training (Wilczynski, 2015). Another researcher added to that list by indicating that having student engagement, reducing barriers, including faculty support, managing safety and liability, and providing sustainable funding was critical to the success of a makerspace (Forest et al., 2014). However, the current efforts to identify best practices focus on the outcomes versus the route towards success, where the journey towards success produces valuable insights for efficiency and strategies in making a makerspace.

To understand how success is achieved, we sought to understand the beginning narratives of engineering-based academic makerspaces at higher education institutions, as described from the perspective of those who played a formative role in the development of the university's makerspace. The beginning narratives of eight various university makerspaces are investigated for the best practices (or shared strategies) in the formation of a university makerspace. We utilized a semi-structured interview protocol focused on the topics of culture, access, design, and unique aspects to the makerspace, where nine leaders from eight U.S. university makerspaces participated in this study. Through interviews, the participants shared the struggles, strategies, and insights involved during the formation of the makerspace. Then, the interview data were analyzed for major emergent themes and supplemented with makerspace profiles that summarize how each space got started. We also crafted a comparison chart that reports the type of institution, funding sources, access, and management models.

Given that no makerspace is the same, the best practices and comparison chart presented in this dissertation are aimed at providing makerspaces of all types with essential insights that can allow for an approach and mindset for success. Even so, most of the makerspaces looked to the Georgia Tech model; it is likely that the reason for following the Georgia Tech model is because in the Georgia Tech model, students want to use the makerspace, students are actually using the makerspace, the model has remained sustainable over time, and students are feeling empowered in the makerspace. These aspects are facilitated by instilling a need for students to use the makerspace, making the makerspace and resources accessible, being adaptable to changing circumstances (e.g., space constraints, fluctuations in financial support, etc.), and developing clear direction in the makerspace. Clearly, not every university space has the same means and resources that the Georgia Tech model has, but makerspaces have opportunity and the ability to create a need, accessibility, adaptability, and direction. Through instilling these best practices in a makerspace, leaders are able to provide opportunity for students. Moreover, these best practices are applicable to other types of makerspaces and other types of spaces/communities as a means to allow for a body of users or community members who are engaged and fulfilled by the space or community.

7.6 Contribution 5: Implications for Engineering Design

In summation, we have three sets of themes that have emerged from this dissertation work (see Figure 22): learning in makerspaces, pathways into makerspaces, and best practices of makerspaces. Together, the three sets of themes highlight the value of invitation, structure, support, engagement, inclusivity, openness, learning, inspiration, creativity, and adaptability. Through examining makerspaces via learning, pathways, and best practices, we have been able to capture the different dimensions of a makerspace, enabling us to extract the essence and value of the university makerspace. First, support and direction forward a woman student's pathway into the makerspace, along with their belief in themselves and their ability to engage in design and creativity. Second, the value of devising and gaining skills through more of a need allows for the creative inspiration and the desire to engage more in the design process. Third, a woman student's ability to adapt to situations (both in the design skills and in their pathways) promotes a more sustainable and usable skillset.

Figure 22: Collective themes on learning, pathways, and best practices of makerspaces

The significance of these themes collectively can also be understood on more practical terms. From this work, it is clear that a makerspace "is more than just a room full of tools." The tools coupled with the culture create the makerspace. The culture should highlight support, first and foremost. This is achieved by nurturing a culture of openness, where failure and asking for help are the foundation of learning in a design-centered environment. In this design-centered environment, the open-ended nature of projects and problems can create barriers and be overwhelming since students are not attune to engaging in problems without answers. Herein, it becomes essential to have instruction and direction in the makerspace that help students to hone in on tool/technical knowledge as they engage in engineering design projects; also, providing example projects with instructions will launch students into developing skills and creating projects when they are uncertain as to where to even start in the makerspace. This is one means to lower barriers to entry. Further, lowering barriers to entry is evidenced in the accessibility of the space. Accessibility is in visibility, recurring exposure, and inclusivity for everyone. This is particularly achieved by keeping the heart of the makerspace about engineering design and fostering learning in the makerspace through projects and machines/tools. To create opportunities for learning and engaging in engineering design for women students, we suggest the following:

- Engineering design workshops, classes, or online tutorials to allow for lower barriers to entry and learning,
- Arts & crafts at the front to show inclusivity,
- K-12 initiatives to spark interest and support in youth, and
- Online presence/signage to help people negotiate the culture.

While women are an underrepresented group both in engineering (Labor, 2017) and as participants in makerspaces (Bean et al., 2015), the gendered experiences of women students in learning and their pathways demonstrate that makerspaces offer women students a means to explore creativity and find the empowerment of design. However, with the notion that 81% of the demographic participating in the maker movement identify as men (Make/Intel, 2012) and the whispers of societal constructions that assign gender to tools, designing, and making (Meyer, 2018), women are still amidst the changing narrative. Through intentional culture changes in how engineering design is facilitated in makerspaces, women can become a part of the narrative.

7.7 Claims for Makerspaces

In the beginning of this dissertation, we articulated the claims and potential benefits associated with the makerspace. In the following, we evaluate these claims based on the findings provided in this dissertation.

7.7.1 Claim for Creativity

Various claims articulated how makerspaces offer a means for creative endeavors amidst the physical building and acquisition of other skills:

- Makerspaces are seen as an avenue to inspire creative, critical problem solving via individual's constructing and iterating hands-on designs, thereby providing a means to acquire specified 21st-century skills (Johnson et al., 2015).
- Makerspaces offer the opportunity to learn creative thinking from building models, creating art, and visualizing ideas (Root-Bernstein & Root-Bernstein, 2013).
- Makerspaces draw upon the natural human desire to make and provide a means to inspire students in creativity, curiosity, independence, determination, and grit (Barron & Barron, 2016; Fleming, 2015; Halverson & Sheridan, 2014).

In this work, we found that women students are learning by doing and iterating; moving into a realm of problem solving, critical thinking, and creativity; and developing an adaptable and transferrable skillset that allows for resilience, reflection, confidence, and patience.

7.7.2 Claim for Agency

The makerspace is also considered a way for individuals to become empowered and take control of their own learning.

- The act of making encourages an individual to become more active by taking control and responsibility for their own learning (Martinez & Stager, 2013, 2014).
- The inherent engaging and interdisciplinary nature of the makerspace empowers agency in young people as a means to drive change in their communities and in a future not yet imagined (Davee et al., 2015; Johnson et al., 2015).

Women students are taking control of their own learning in the makerspace and in their communities by engaging in learning and inspiration; forwarding their own ability to more fully engage in design; opening up doors and instilling belief in oneself; and changing the narrative to include that women are a part of design. Further, the makerspace allows for empowerment by providing structure and direction for women students.

7.7.3 Claim for Collaboration

Furthermore, the makerspace is identified as a collaborative environment where knowledge is shared among community members.

- Makerspaces exhibit daily occurrences of collaboration, discovery, and innovation (Radniecki et al., 2016).
- Tools, machines, ideas, and knowledge are shared amidst the use of advanced technologies and the making of projects in makerspaces (Pernia-Espinoza et al., 2017; Sheridan & Konopasky, 2016).

As shown in the typology of learning and the learning model, the makerspace supports an interactive and dynamic learning between cognitive, interpersonal, and intrapersonal competencies. More specifically, competency in collaborating, design, manufacturing and tool knowledge, ingenuity, and communicating are developing together in a community where cultural knowledge is as influential as content knowledge.

7.7.4 Claim for Education

Final claims about makerspaces surround their impact on the educational system.

- This type of collaborative learning environment is believed to be the next generation classroom (Colegrove, 2016).
- Makerspaces are believed to be the ultimate bridge between university and industry, especially for STEM-related fields (Pernia-Espinoza et al., 2017).
- It is believed that an educational system rooted in making has the potential to revolutionize thought on pedagogy and learning (Kurti et al., 2014b).

Universities and education are moving towards integrating makerspaces into the curriculum. As such, this type of collaborative learning environment is the next generation classroom, because the learning is dynamic and beyond only content knowledge, and pathways are diverse and varied. Makerspaces are a bridge between university and industry because the women students who engaged in a makerspace have honed in on technical skills; have more fully engaged in design; have moved into a realm of problem solving, critical thinking, and creativity; have opened up doors for creativity and learning; have come to believe in their abilities as an engineering and designer; and have developed an adaptable and transferable skillset. An educational system rooted in making will revolutionize thought on pedagogy and learning because the acquisition and exchange of knowledge and learning – as evidenced in the typology of learning and learning model – is unlike the learning occurring in the traditional classroom setting, in project-based or active learning, and in student competition teams. For example, in student competition teams, students orient professional skills into self-management, task management, and team management (Bland et al., 2016); and identify five main leadership behaviors (ideal behavior, individual consideration, project management, technical competence, and communication) and six ancillary behaviors (collaboration, training & mentoring, problem-solving, motivating others, delegation, and boundary-spanning) (Wolfinbarger & Shehab, 2015).

7.8 Overview

Overall, learning in engineering design emphasizes hands-on, real-world experiences that engage critical thinking, problem-solving, and iterating through the design process. While advances had been made in studying the learning in engineering design in the classroom, challenges persist in efforts to study the hands-on, real-world experiences occurring in university makerspaces. In this work, we provide a methodological approach for studying complex phenomenon, showcase the learning and pathways of women students in makerspaces, and articulate the best practices of university makerspaces.

7.9 Limitations

There are numerous limitations to be considered in this work. First, the data corpus is self-reported data, which is highly based on interpretations of the questions that the interviewer asked. Second, the sampling strategies may miss students who are not part of the social network that we engaged in. For instance, while we talked to numerous women of various backgrounds and ethnicities, there were no women of an underrepresented minority who participated in this study. Limitations also occur from narrowing our scope to university makerspaces and women. Further, the focus on interview data lacks triangulation with other methods, and the lack of prior research challenges the methodological choices that we use in this dissertation.

7.10 Future Work

One aspect towards navigating future research is to move towards examining other claims associated with makerspaces, whether through the current data acquired or through future data acquisition. In this work, we focused the claims centered on learning. Even with the focus on learning, there remain areas exposed and ripe for analysis, such as examining the benefits of physical model building, teamwork and community, self-learning, and motivation. For example, while an individual's engagement and motivation will increase when given the opportunity to make contextualized and personalized decisions during instructional or training activities (Cordova & Lepper, 1996), evidence is yet to be provided for how engagement and motivation increase in the makerspace setting through contextualized and instructional activities. Our future works seeks to examine the findings from the studies presented in this dissertation with a longitudinal quantitative study examining student design self-efficacy and makerspace involvement.

Further, these 868 pages are rich in themes of learning, education, social constructs, communication, etc. Patterns in the data suggest further analysis using a priori frameworks such as Bronfenbrenner's ecological systems theory, activity theory, and educational theory of apprenticeship, along with state change models (e.g., how a student goes from fear to confidence) or other potential frameworks associated with more in-depth analysis of pathways into makerspaces, communities of practice, situated learning, engaging females in STEAM, etc. Assuredly so, this qualitative research dives into the stories of these women students and demonstrates numerous, yet diverse implications for engineering design and pedagogy.

Activity Theory. In activity theory, the individual has a goal and in order to get to that goal, the individual uses tools or mediating artifacts that are impacted by the rules and the division of labor of a community. Throughout the interviews, there was a common goal across all participants of needing to make a gift for someone. For activity theory, the different equipment in the makerspace such as the laser cutter, 3D printer, or mill and lathe became tools that the individual would use to make the gift. Further, a community's rules of when and how tools are to be used impact the individual's ability to make a gift. For example, a makerspace that has the rules that research and class projects get precedence over personal projects would impact an individual's ability to achieve that goal of making a gift. Still, when a goal is hardwired into an individual, they abide by the rules and build relationships with community members to gain access to the makerspace outside of the normal public open hours.

Bronfenbrenner's Ecological Systems Theory. An individual is constantly interacting with different ecosystems, and Bronfenbrenner's ecological systems theory aims to understand how an individual's development is influenced by the interaction between their inherent qualities and the environments that they are exposed to. As such, the interviews conducted in this study revealed how growing up, these individuals are exposed in some form to a "maker" mindset. The participants themselves ranged in their own participation in making activities in their youth, but they all had someone in their upbringing who was fixing or creating things.

Educational Theory of Apprenticeship. Through apprenticeship, an individual is immersed in an environment where they are trained in how to do some form of activity associated with that environment. With makerspaces, these participants are in a space dedicated to making. They are trained to make things, whether for class, research, or personal endeavors. In the interviews, the students describe how someone taught them how to use a machine and showed them how to use it. They even describe how they have to teach themselves if no one immediately knows what to do and how they access online resources in order to learn how to do something. Thereby, the apprenticeship model expands beyond simply the people in the surrounding physical space.

From analyzing the interview data with specific theories in mind, this allows a more in-depth understanding of the way that making activities are mediated, how the environment has impacted these students desire to make and design, and how students are developing design competence in these makerspaces. Further work will analyze the data through open coding and other data analysis approaches to continue to contribute to the understanding of makerspaces.

Moreover, additional future work seeks to gain insights from men who are involved in makerspaces. It is expected that men will have similar learning types; however, it is anticipated that their pathways into the makerspace may differ in comparison to women students. By investigating both men and women, we will be able to compare the narratives for how men and women explore, learn, and interact with the makerspace. These findings would provide implications for engineering education, such that we are able to identify how hands-on learning, makerspaces, and making impact the student experience, which thereby informs the measures that educators must take to support and create programs that allow for diverse pathways and holistic formation to all students.

7.11 Reflections

Since the nature of this dissertation involved reflexive interviewing, I wish to provide my own quick reflection on the work. Being a mechanical engineer, taking on the challenge of immersing myself in the qualitative realm was far from what I anticipated. After three years of the endeavor, I wish for engineering design researchers to understand the rigor that goes with qualitative methodologies and methods. We seemingly think that we can pick up different methods and use them as we need, but with qualitative work, your patience and humility are tested time and time again. Ultimately though, sharing the voices of these women students is the highest valued reward of this work.

APPENDIX A. IN-DEPTH PHENOMENOLOGICALLY BASED INTERVIEW JOTTINGS

Interview One

- Interest in how you got involved
- Before GT; Growing up, what was is like for you with creating or making things
- attracts you to this space or types of spaces
- inspires you to use the space
- elementary school
- High school
- Keeps you going
- Person who has influenced you
- Clubs, activities
- What did you do growing up, things you were involved in

Interview Two

- What you do
- What do you call what you do
- How do you go about making something
    - Walk me through the process
- Describe experiences you have
- Typical week, day
- Interaction with other students, faculty, staff --- daily, monthly, etc.
- What is it like for you to be involved in this space
    - In making
- Roles
- Rules
- How does using the space come about in a typical week
- Dynamic of class + leisure + anything else come into fruition in makerspace … in making
- For someone who has never been here, how would you characterize/talk about the space

Interview Three

- Timeline
- For someone who has never been here, how would you characterize it
- What do you call what you do here
    - Making, crafting
- Given what you have said about your experience before + now, how do you understand __ in your life
    - What sense does it make to you
- Where do you see yourself going in the future?
- How has this changed/shaped your life?
    - Role as student, learner
    - Types of skills
    - Way of thinking
    - Goals + how to achieve them
- Takeaways
- What in your life do you attribute to this space?
- Experiences = important, impactful
- Speak to what is like being female in these spaces
- Confidence
- Role of space/making in life?
- How do you see yourself (your role) in these spaces?

APPENDIX B. **SINGLE, TARGETED INTERVIEW PROTOCOL**

Thank you for agreeing to meet with me today. I have us scheduled for an hour together. Does that still work for you? I want to honor our time constraints today. If we reach the hour and you would like to expand on the questions more, I would compensate you for the additional time. Nevertheless, while I encourage you to elaborate on your answers to my questions, there may be times when I redirect, so that we may be sure to cover all the topics in the hour.

<go over IRB>

This meeting is focused on your making, design, and learning experiences as a woman involved in the makerspace.

So I want you to think of your experiences making and what you've learned throughout these experiences. I want you to imagine that you've had this toolbox and every time that you've learned something, you add it to your toolbox. And what I'm interested in is what is in this toolbox because of your involvement in the makerspace, so what it looked like before and what it looks like now.

In order to help you navigate the loads of things that you've done in your life, I want you to first start off with creating a timeline of your making experiences growing up to now.

Could you highlight the point for where you began your involvement in the makerspace at Georgia Tech?

Now, looking at this region for growing up to your involvement, what would you say was in your toolbox?

Now since your involvement, what has changed in your toolbox?

What has changed in regards to:

- Knowledge in course-related topics such as design, manufacturing, materials
- Ability to understand and navigate a specific culture or community
- Creativity
- Personal growth and your perspective on making
- Navigating your identity as a woman in the makerspace
- Communication skills
- Leadership skills

Has your way of thinking through a problem changed? Could you walk me through an example?

How would you characterize *how* you learn in the makerspace?

What are some of the things that you have learned how to make in the makerspace?

Overall, how has your experience in the makerspace impacted your life?

APPENDIX C. **CALCULATING INTER-CODER RELIABILITY**

		Interviewer									
		Learning by doing	**Learning by others**	**Content**	**Cultural**	**Ingenuity**	**Self development**	**Communicating**	**Managing**	**Total**	
Other coder	**Learning by doing**	10	0	1	0	1	1	0	0	13	0.109244
	Learning by others	0	13	0	1	0	1	0	0	15	0.12605
	Content	1	1	10	1	1	1	0	0	15	0.12605
	Cultural	0	1	0	23	0	2	0	0	26	0.218487
	Ingenuity	0	0	2	0	4	0	0	0	6	0.05042
	Self development	2	0	2	6	1	24	0	1	36	0.302521
	Communicating	0	0	0	0	0	0	2	0	2	0.016807
	Managing	0	0	0	2	0	0	0	4	6	0.05042
	Total	13	15	15	33	7	29	2	5	119	0.183391
		0.109243697	0.12605042	0.12605042	0.277310924	0.058823529	0.243697479	0.016806723	0.042016807	0.756303	0.701574

Total Instances	119
Total Matches	90
Total Nonmatches	29
Cohen's Kappa	0.70157385

Total Instances	120
Total Matches	91
Total Nonmatches	29
Percent Agreement	0.758333333

APPENDIX D. **NVIVO INTER-CODER CALCULATIONS**

Code	File	File Size (characters)	Kappa	**Agreement (%)**	A and B (%)	Not A and Not B (%)	**Disagreement (%)**	A and Not B (%)	B and Not A (%)
1 Learning by doing	Interview 1	82008	0.9330	99.72	2.00	97.72	0.28	0.00	0.28
1 Learning by doing	Interview 2	31091	0.6951	87.11	23.42	63.68	12.89	10.93	1.97
2 Learning by others	Interview 1	82008	0.7744	96.39	6.96	89.43	3.61	1.71	1.90
2 Learning by others	Interview 2	31091	0.4151	97.62	0.87	96.75	2.38	2.38	0.00
3 Content knowledge and skills	Interview 1	82008	0.8978	98.86	5.34	93.53	1.14	0.21	0.93
3 Content knowledge and skills	Interview 2	31091	0.6512	89.79	12.58	77.21	10.21	2.44	7.76
4 Cultural knowledge and skills	Interview 1	82008	0.7697	91.29	20.90	70.40	8.71	6.22	2.49
4 Cultural knowledge and skills	Interview 2	31091	1.0000	100.00	3.21	96.79	0.00	0.00	0.00
5 Ingenuity	Interview 1	82008	0.8874	99.22	3.19	96.03	0.78	0.26	0.51
5 Ingenuity	Interview 2	31091	0.6756	94.89	5.98	88.91	5.11	5.11	0.00
6 Self Development	Interview 1	82008	0.7196	91.29	14.86	76.43	8.71	3.37	5.33
6 Self Development	Interview 2	31091	0.6936	88.33	19.06	69.27	11.67	0.00	11.67
7 Communicating	Interview 1	82008	1.0000	100.00	2.47	97.53	0.00	0.00	0.00
7 Communicating	Interview 2	31091	1.0000	100.00	0.00	100.00	0.00	0.00	0.00
8 Managing and leading	Interview 1	82008	0.9417	99.67	2.75	96.92	0.33	0.00	0.33
8 Managing and leading	Interview 2	31091	0.9723	99.45	10.84	88.62	0.55	0.55	0.00

Average for all nodes & sources (unweighted)			0.7789	95.85	8.40	87.45	4.15	2.07	2.07

SEF	TA	TU	Weighted A and B (%)	Weighted Not A and Not B (%)	Weighted A and Not B (%)	Weighted B and Not A (%)
95.81	99.72	100.00	164016.0	8013821.8	0.0	22962.2
57.70	87.11	100.00	728151.2	1979874.9	339824.6	61249.3
84.01	96.39	100.00	570775.7	7333975.4	140233.7	155815.2
95.94	97.62	100.00	27049.2	3008054.3	73996.6	0.0
88.89	98.86	100.00	437922.7	7670208.2	17221.7	76267.4
70.73	89.79	100.00	391124.8	2400536.1	75862.0	241266.2
62.19	91.29	100.00	1713967.2	5773363.2	510089.8	204199.9
93.79	100.00	100.00	99802.1	3009297.9	0.0	0.0
93.09	99.22	100.00	261605.5	7875228.2	21322.1	41824.1
84.26	94.89	100.00	185924.2	2764300.8	158875.0	0.0
68.93	91.29	100.00	1218638.9	6267871.4	276367.0	437102.6
61.92	88.33	100.00	592594.5	2153673.6	0.0	362832.0
95.18	100.00	100.00	202559.8	7998240.2	0.0	0.0
100.00	100.00	100.00	0.0	3109100.0	0.0	0.0
94.34	99.67	100.00	225522.0	7948215.4	0.0	27062.6
80.26	99.45	100.00	337026.4	2755284.4	17100.1	0.0

81.24	95.85	100.00

APPENDIX E. **THE LEARNING TYPOLOGY V1**

Makerspaces: How is learning being accounted for in the makerspace?

1-HOW

1.1 "Learning by doing"

    1.1.1 By lack of success (mistakes, failure)
    1.1.2 By struggling
    1.1.3 By practicing
    1.1.4 By prototyping/iterating

1.2 Learning by being

    1.2.1 By observation
    1.2.2 By interactions
        1.2.2.1 By giving help
        1.2.2.2 By receiving help
        1.2.2.3 By conversation

2-WHAT

2.1 "Toolbox of Design"

    2.1.1 Technical Learning
        2.1.1.1 Terminology
        2.1.1.2 Tools (Machines, Computer software, Materials)
            2.1.1.2.1 How to use
            2.1.1.2.2 What to use
            2.1.1.2.3 When to use
    2.1.2 Design Process
        2.1.2.1 Identifying Goals, Aims, Direction
        2.1.2.2 Generating ideas/solutions
        2.1.2.3 Prototyping (building, modeling)
        2.1.2.4 Instilling Efficiency (using time and resources wisely)
        2.1.2.5 Using Creative Outlets or Generating Creative Solutions
        2.1.2.6 Recognizing Barriers/Limitations
    2.1.3 Problem Solving
        2.1.3.1 Incorporating Resourcefulness
        2.1.3.2 Stepping Back or Using Reflective Reasoning
        2.1.3.3 Asking Questions
        2.1.3.4 Making connections
            2.1.3.4.1 Applying knowledge
            2.1.3.4.2 "Seeing something"
                (a <concept from other domain> would work for solving this problem)
            or
                (what this person is working on could help me to solve problem)
            2.1.3.4.3 Achieving Ah-ha moments/tangible realization

2.2 Life Skills

2.2.1 Intrapersonal
- 2.2.1.1 Values (time and effort)
- 2.2.1.2 Preferences
- 2.2.1.3 Passions/Interests
- 2.2.1.4 Perspective
- 2.2.1.5 Emotional Responses or Feelings (pride, fearless)

2.2.2 Interpersonal
- 2.2.2.1 Culture (roles, rules, etc.)
- 2.2.2.2 Social
- 2.2.2.3 Communication
  - 2.2.2.3.1 To help others
  - 2.2.2.3.2 To explain concept
  - 2.2.2.3.3 To work together or collaborate
  - 2.2.2.3.4 To engage others

APPENDIX F. **THE LEARNING TYPOLOGY V2**

ID	Code	Description	Example
		HOW	
1	LEARNING BY DOING	discussion of learning by physically doing and making	Like I'm very hands-on. I have -- to learn something, I have to do it.
1.1	Through failures and mistakes	discussion of failing or making mistakes and learning from those failures or mistakes	And so I went in and I'm like, "Okay, so let me just take this wood and cut it down." And I cracked a piece of wood. And I'm like, "Shoot, okay, I can't do it this fast."
1.2	Through struggles	discussion of struggling and not knowing what to do but still going through and learning from that	Of like how the machine -- in the same way that like people believe flipped classrooms work is of you struggling through a problem, right. … That same idea or concept is how like I think I've learned through design.
1.3	Through practice	discussion of making projects in order to get the hang of how a tool works or how to make something	Like once you've made something four or five times, you're fast, you're good at making it. You know all the shortcuts. You know where it's going to give you trouble.
1.4	Through iterations	discussion of repeatedly making the same thing and learning from those iterations	But I made -- like the first one, it was too big. And the second one, the engraving didn't come out really well. But about the fourth one, I realized I had misspelled [something]. I did all those iterations.
1.5	Through guidance	discussion of being trained on or guided through making something	"Okay, well, come in for training, and I'll teach you how to do this, and then we can work together to make what you want to create, a feasible, tangible thing."
2	LEARNING BY BEING	discussion of being present in a space and learning from just being there and interacting in that space	"Why don't I go hang out there and see what I can do with my project," I think is a lot of what happens. Which is pretty cool of like it's not something you think about, but I think it's something that I've observed, that it's very cool.
2.1	Through observation	discussion of observing what someone is doing or saying	And they're like, "Oh, how can I apply your knowledge to what I'm doing?" I think it's a lot of what I've seen and experienced myself with like how people learn in that environment.
2.2	Through helping (giving or receiving)	discussion of giving or receiving help in order to learn a tool or figure out what to do (one person is a helper in this situation)	I can be like, "Hey, I want to try this. Tell me if it's stupid, or if there's a different way I should do this." And they'll be like, "Yeah, you could totally do this. Like let me help you."
2.3	Through conversation/just talking	discussion of when interacting with others and talking with them results in learning	And I think it's a lot of the way that people learn in the machine shop, from what I've seen or like encountered, is just talking to people.
3	NOT LEARNING BY DOING	discussion of when learning is not occurring	Yeah, it's something you've done because you've designed things wrong, but how do you learn from that to make it right versus just accepting that you've failed and maybe could try something else, if that makes sense.
3.1	Not learning from being successful	discussion of when one does not learn because there was no failures or mistakes	I've learned a lot through those [mistakes] rather than the project that I've like just laser cutted, and it worked fine, because you know, you learn to like make something cool, but you don't learn from that.

3.2	Not learning from textbooks/lectures	discussion of how textbooks and lectures alone do not lend to learning	It's much more important to be able to fix problems even if you don't have all of the information, rather than just have textbook knowledge on stuff.
3.3	Not learning from improper training	discussion of when a lack of proper training results in failure to learn (e.g., someone doing something for you or going through quickly)	Someone can teach you and train you on how a machine works, but I like to spend time just like doing things on a machine.
WHAT (Design)			
A	TECHNICAL TERMINOLOGY	words or phrases that are learned from involvement in making or makerspaces	It's super-useful to know the difference between like bitmap and vector images.
B	TECHNICAL TOOLS(Machines, Computer software, Materials)	competence in using machines, computer software, or materials	Anything you learn, like 3D printing, any of the tools, the 3D print, the CNC mill, the bandsaw, all of those are tools in your toolbox of design.
B1	How to use	competence in knowing how to use a machine, computer software, or material	I could only know how to laser cut, but I could be awesome at it, and I could teach people how to laser cut things that would make them good at different things. So I think it's cool to learn from other people in the shop.
B2	When to use	competence in knowing when to use a machine, computer software, or material	If you do that, you're probably going to want to use these kinds of metals.
B3	How it works	competence in knowing how a machine works, how a computer software works, and how a materials works - aka the properties of the material	Sewing is a little different since your material is so flexible, you have to kind of be aware of how the material is going to all come together.
C	DESIGN THINKING/PROBLEM SOLVING PROCESS	discussion on intuition and problem solving skills for designing or making something. Note: this section is posed as 'learning how to __'	I enjoy the process of having a problem and like being able to solve it through being like this is the list of the possible outcomes that I think are why this problem is occurring. Let me tick of the boxes of like oh.
C1	Identify Objectives (Goals, Aims, Direction)	discussion on what do you want to or need to do	How do you make like an idea or a concept that is so easy that you could hand it to like a kid and make it work? That was our goal was to make something simple.
C2	Interpret the Problem	discussion on what is wrong or what is the problem that needs to be solved	"What's your problem?" And then someone will be like, "Oh, I need to build a box."
C3	Generate ideas/solutions	discussion on ideas, concepts, or ways to achieve goal or solve problem	Okay, so what we did was we came up with a bunch of ideas. It was like a session where you're like nothing is a -- like don't say no.
C4	Prototype, Build, and Model	discussion on physically representing the concept or building something	And then realizing that two 45-degree angles come together to make a 90-degree angle. So it was like that was such a dumb thing that we should have realized. But doing that and be like, "Oh, okay, visually I understand how this works now."
C5	Be Resourceful and Efficient	discussion on using time and resources wisely	Let me think what I can do with what I have.
C6	Fix Something	discussion on repairing an object to a better condition or fixing an item	"How are you going to fix that?" And then like watch him fix it, and he'll like explain to me what he's doing. So then like the next time the [machine] or something else leaks, I'll be able to know how to fix it.

C7	Understand the Meaning or Purpose	discussion on why is one doing what they are doing and finding meaning to the work that one is doing	Or someone will walk by see me spending three hours sanding something be like, "What are you making? Like why are you spending so much time on this?" I'm like, "Well, I'm making this. And it's super-cool," and I talk about it.
C8	Incorporate Unorthodox Means or Strategies	discussion on using unique ways in the design process and to solve a problem (e.g., going to a toystore)	We were just playing with kids' toys of how kids blocks join together. And that's when we got -- we found -- we saw those kid's blocks that are like a snake that you can -- you could make it a different shapes. And we were like, "Okay, what if we're trying to do that with that idea of taking multiple blocks and making this?"
C9	Examine or Rectify Barriers/Limitations	discussion on what is preventing someone from achieving their goal or solving the problem, or how one is limited in achieving a goal	But then you see a lot of people that start off with designs and 3D printing. And then because they don't know other tools, then they're stuck on 3D printing, and then it becomes inefficient for them to continue 3D printing for their current project.
C10	Make Connections	discussion on connecting an idea from one domain to another or realizing something that could help to solve a problem Note: not to be confused with connecting with people	Yeah, I think a lot of people do random things all the time in the shop that don't seem inter-related, but when you talk to people and you're, "Like I made this cool thing." And they're like, "Oh, I'm trying to do something." And then people are able to connect that together. And then make something cool.
	WHAT (Life Skills)		
10	INTRAPERSONAL - PERCEPTIONS AND ATTITUDES	discussion on how one perceives things and what they have come to understand about themselves	Yeah, I think that I've never not enjoyed being in the shop. But that might be a me thing.
10.1	Learning what one values	discussion on what one considers useful or important; can be stated explicitly or implicitly (e.g., putting time and effort into a project OR someone can even value feeling validated)	Like I really -- I get a lot of validation -- I really like it when people use my stickers and like have them on things.
10.2	Learning what one likes or dislikes	discussion on what one has come to like or does not like	And I was like, "Well, I just like making stuff."
10.3	Learning what one is passionate about or interested in	discussion on the things that excite a person, on what their passions or interests are	And then they're able to 3D print something. They're like, "This is tangible of what like I'm passionate about."
10.4	Gaining perspective	discussion on how one perceives things, usually in the form of seeing things more holistically, rectifying one's attitude or mindset	And I think it's a lot of the way that people learn in the machine shop, from what I've seen or like encountered, is just talking to people.
20	INTRAPERSONAL - CHARACTER, EMOTIONS, FEELINGS	discussion on how one has developed character	It's like, "Oh, no. Are they not going to respect me because I don't know the answer to this question? Are they not going to listen to me? Are the other [student workers] going to think I'm less competent?"
20.1	Learning Resilience	discussion on coming back from a bad situation – toughness, grit	After all those little, tiny challenges you faced, it finally came together, and you made the thing you wanted to do.
20.2	Learning Fortitude	discussion on the ability to confront fear – courage, endurance, strength	At first it was a little scary for me. … But now I'm like -- I'm competent enough in all the rooms, but there's a lot of tools that I'm not totally solid on.

20.3	Learning Prudence	discussion on judging between actions and what action is appropriate at a given time – time management, priorities	Sometimes I'm just sitting there doing homework if no one comes in and it's quiet. If I have a lot of work to do, I prioritize work, because I'm a student.
20.4	Learning Patience	discussion on steadily going through a process or persevering	And so I had like half a shelf, and I took it outside to paint it, and the legs fell off. I was like, "Okay, need to be more patient."
20.5	Learning Confidence	discussion on being more comfortable or confident in completing a task - motivation, pride	And so I feel much more confident knowing that if someone comes to me with a question I can't answer, I kind of know the steps to walk through the problem solving.
20.6	Learning to overcome unwanted emotions	discussion on overcoming and no longer having an unwanted emotion	Now that I know people in the shop and I'm not afraid to talk to them, they're like normal-ish people.
20.7	Recognizing one's fear or negative emotions towards a situation	discussion on when one is afraid to do something or has an emotion that negatively impacts their perspective	I'm very frustrated at it, my perspective is not going to help me at that point, because I'm frustrated, and I just need to take a step back.
30	INTERPERSONAL	discussion on skills that pertain to working with others	He's been doing woodworking projects since he was eight. So if like he's around, I'm going to ask him for advice, because chances are he's going to be able to give better advice than me who has only been woodworking for about a year now.
30.1	Learning what the culture is like (roles, rules, etc.)	discussion on what are the nuances of the culture, what are the roles and rules in the culture, how is it managed	A lot of people come in here and make stuff for class, or a lot of people typically come in to make gifts or little pet projects of their own.
30.2	Learning how to communicate to others	discussion on how one has picked up on social cues and is able to communicate ideas or concepts to others; also, able to describe what they are working on, or working with people to achieve a goal	I can tell because if you've never been there before, you have a problem you need to solve, and you don't know what to do, they'll walk in, and they'll look like this.
30.3	Learning how to manage, network, and plan	discussion on working on and handling more of the back-end tasks for keeping the space running or planning events	When I'm like on the shift as a [student workers], like my main goal is to keep people safe, right, whether I'm in the wood room and like watching people, making sure nobody drills through their hands, making sure everybody's got their hair tied back and has got like safety glasses on, and everything.
30.4	Learning how to connect with people or engage them in what they are doing	discussion on relating to people (whether person-to-person or getting them excited about the work that they are doing)	I've learned through teaching is being able to connect with someone allows them to understand you better.

APPENDIX G. **THE LEARNING TYPOLOGY V3**

Part I: Axial Codes

ID	CODE	Definition	Coding Rules	Examples
1	**LEARNING BY DOING**	Discussion of learning by doing - learning through experiences as a direct result of one's own actions.	Code when participant uses words such as "hands-on" or "hands-on learning," "need to do it," "need to make it." Reflects the concept "If I do it, I know it." *This code can be by itself or paired with the codes below.*	Like I'm very hands-on. I have -- to learn something, I have to do it.
2	**LEARNING BY WAY OF OTHERS**	Discussion of being present in a space and learning from just being there and interacting in that space.	Code when participant discusses the importance of being present in the environment to learn and talking with other people. Words like "hanging out," "spending time" might appear in this code. *This code can be by itself or paired with the codes below.*	"Why don't I go hang out there and see what I can do with my project," I think is a lot of what happens. Which is pretty cool of like it's not something you think about, but I think it's something that I've observed, that it's very cool.
3	**DESIGN PROJECT**	Discussion on the projects that one makes.	Code when participant talks about the different projects that they have made, whether "this is what I have made," "this is why I made it," or "this is how it works." *This code can be by itself or paired with the codes below.*	...if I'm like laying vinyl, and it's like slightly off center, I'm like, I just have to start over again. Which is nice, because like, for these, for example, I just like peel the vinyl off and like clean it and like put new vinyl.
4	**DESIGN TERMINOLOGY**	Discussion using words, phrases, or language that are particular to the design or making activities.	Code when participant uses jargon such as "STL file," "raster," "bitmap," "dowel," "lock and key," etc. that are characteristic in the making of a design and using the design equipment. This code highlights the word, phrase, or language that is specific to the design tools and activities.	It's super-useful to know the difference between like <u>bitmap</u> and <u>vector</u> images.
5	**DESIGN TOOLS**	Discussion on the tools (physical and conceptual), mediums, means, or equipment that is used in order to create something; knowing how to use the tool when to use the tool or how the tool works.	Code when participant describes the devices and materials that they use and have learned about. This code does not look at depth of their understanding, but is associated with developing and acquiring more experience with design techniques, machines, software, and materials. *This code can by itself or used to encompass multiple of the codes below. For example, a participant might describe their understanding of the machine, software, and material in a scenario that is too difficult to create distinctions, which would allow for the code 'design tools.'*	And then we also have them laser cut, which is -- helps them think in the same way of -- like if I -- this would be horrible, but if I wanted to make this using laser-cuttable material, the most you can laser cut is about 1/4 of an inch, comfortably, without burning your product, right.
6	**DESIGN PROCESS** ***Problem Solving***	Discussion on the process to design, problem solve, or incorporate design thinking strategies.	Code when participant broadly goes over their process for a design, their way to solve a problem, or their use of design thinking. A participant can say "It's just like	I enjoy the process of having a problem and like being able to solve it through being like this is the list of the possible

	Process Design Thinking Process		problem solving" or "this is how design is" which means that they are referring to this code. *This code can be by itself or paired with the codes below.*	outcomes that I think are why this problem is occurring. Let me tick of the boxes of like oh.
7	**DESIGN INTUITION**	Discussion on knowing, recognizing, or being cognizant of the situation one is in, specific to design.	Code when participant shares an understanding of there are strategies, resources, and barriers that all have to be taken into consideration when creating a design. The world offers connections to design and here, this code captures when the participant makes those connections. *This code encompasses the codes below.*	The thing with the topic of health is so big that it was so much easier to pick one thing-- like, the faster you can narrow down what you were doing, the more energy you could focus on what your final project was going to be.
8	**MAKERSPACES**	Discussion on learning about makerspaces and what all a makerspace entails.	Code when participant reports on the makerspace and what they know about the way the makerspace functions and what it is like to be in the makerspace. *This code can be by itself or paired with the codes below.*	I think I would talk about mainly the privacy aspect of it. Because it's -- like honestly, like I cannot highlight enough that that's my favorite like, one, the fact that you can go like anytime once you're like trained.
9	**ATTRIBUTES**	Discussion on the characteristics or attributes that one has learned, gained, or practiced.	Code when participant conveys an intrapersonal understanding of themselves or the makerspace, or the participant simply describes a scenario that showcase their growth, motivation, and developing of character	Or someone will walk by see me spending three hours sanding something be like, "What are you making? Like why are you spending so much time on this?" I'm like, "Well, I'm making this. And it's super-cool," and I talk about it.

Part II: Complete Codebook and Coding Rules

ID	CODE	Definition	Coding Rules	Examples
1	**LEARNING BY DOING**	Discussion of learning by doing - learning through experiences as a direct result of one's own actions.	Code when participant uses words such as "hands-on" or "hands-on learning," "need to do it," "need to make it." Reflects the concept "If I do it, I know it." *This code can be by itself or paired with the codes below*.	Like I'm very hands-on. I have -- to learn something, I have to do it.
1.1	Failing	Discussion of failing or making mistakes, to fall short in succeeding to achieve a goal, or to error in one's action or judgment.	Code when participant points to specific mistakes or failures they made that required them to rethink *how* they were making. Mistakes might be related to the choice of machine, the speed, the steps, or the materials.	And so I went in and I'm like, "Okay, so let me just take this wood and cut it down." And I cracked a piece of wood. And I'm like, "Shoot, okay, I can't do it this fast."
1.2	Struggling	Discussion of struggling through a task or contending with a task while having uncertainties.	Code when participant says things like "I didn't know how" or "I didn't understand at first," as well as "overcome," "struggle," "difficulty." This is distinct from 1.1 in that there is a focus on obstacles such as lack of knowledge that must be worked through, whereas 1.1 points to specific failures and mistakes that needed correction.	Of like how the machine -- in the same way that like people believe flipped classrooms work is of you struggling through a problem, right. … That same idea or concept is how like I think I've learned through design.
1.3	Practicing	Discussion of practicing with tools, machines, software, or material; making projects in order to get the hang of how a tool, machine, etc. works or how to make something.	Code when participant indicates that they have followed the <u>same</u> process over and over again. Words like "perfecting," "getting better at it," might appear in this code.	Like once you've made something four or five times, you're fast, you're good at making it. You know all the shortcuts. You know where it’s going to give you trouble.
1.4	Iterating	Discussion of creating iterations of a design, or making something over again or repeatedly.	Code when participant uses sign-posting such as "first time" or "first try," followed by "second time" This code is distinguished by each "try" reflecting a change <u>in the process or design,</u> whereas 1.3. is just repetition of the same process.	But I made -- like the first one, it was too big. And the second one, the engraving didn't come out really well. But about the fourth one, I realized I had misspelled [something]. I did all those iterations.
1.5	Exploring	Discussion of exploring, tinkering, or playing around in order to create; not having a direct plan.	Codes when participant describes a process that has no clear path. Phrases like "you've just got to <u>play around</u> with it" or "just do it and see what happens."	So, I - I would download one of those basic models. It includes the CAD file and the 3D printing file. Just open the CAD file, play around with it, you know, change some things I want.

ID	CODE	Definition	Coding Rules	Examples
2	**LEARNING BY WAY OF OTHERS**	Discussion of being present in a space and learning from just being there and interacting in that space.	Code when participant discusses the importance of being present in the environment to learn and talking with other people. Words like "hanging out," "spending time" might appear in this code. *This code can be by itself or paired with the codes below.*	"Why don't I go hang out there and see what I can do with my project," I think is a lot of what happens. Which is pretty cool of like it's not something you think about, but I think it's something that I've observed, that it's very cool.
2.1	Observing	Discussion of observing what someone is doing or saying.	Code when participant uses words like "observing," "seeing what others are doing," "listening," "learning from watching."	"How are you going to fix that?" And then like watch him fix it, and he'll like explain to me what he's doing. So then like the next time the [machine] or something else leaks, I'll be able to know how to fix it.
2.2	Collaborating	Discussion of the discussion or collaboration of two or more people who do not fully understand but are working towards understanding or achieving a goal, whether through brainstorming, thinking of new concepts and ideas together, talking to understand together, and working together.	Code when participants point to the importance of relationship, communication, and collaboration with others within makerspaces as important. This is a mutual activity of "talking with others" or other synonyms for talk may be used, such as "working it through with others."	And I think it's a lot of the way that people learn in the machine shop, from what I've seen or like encountered, is just talking to people.
2.3	Helping	Discussion of giving or receiving help in order to learn a tool or figure out what to do; in this process, a person with knowledge (or understanding) giving assistance to a person without the knowledge so as to help them understand conceptually.	Code when participant discusses situations where a person with more knowledge assists, supports, encourages, or engages another who has less knowledge. The participant may be on either side, as the one giving helping or the one receiving help. This code occurs most often when someone has authority in the space, such as a student worker. The distinction between 2.2 and this code is that 2.2 is "working together to understand" and this code has an authority or superior comprehension that assists another, gives advice, communicates experience, offers an opinion based on experience, or provides uninvested guidance.	I can be like, "Hey, I want to try this. Tell me if it's stupid, or if there's a different way I should do this." And they'll be like, "Yeah, you could totally do this. Like let me help you."
2.4	Training	Discussion on training, teaching, or providing direct instruction for someone in order to make them proficient.	Code when participant points to being guided and taught through "training", "steps", "a process", "teaching," or even an "instructional manual." Both 2.3 and this code have a person of greater knowledge providing the help (2.3) or training (2.4). Training differs from 2.3 by the focus on direct instruction, where one is taught a process and told this is what you need to know and this is how you do it.	So like I showed you before how to make it a text to path. Why don't you go and do that again? -- - But, yeah, just, I don't know, but it was like setting the space up slowly, like doing both things, you learn how to use the machines. Learning how to use the machines is manuals. That's how you learn how to use machines.

ID	CODE	Definition	Coding Rules	Examples
3	**DESIGN PROJECT**	Discussion on the projects that one makes.	Code when participant talks about the different projects that they have made, whether "this is what I have made," "this is why I made it," or "this is how it works." *This code can be by itself or paired with the codes below.*	...if I'm like laying vinyl, and it's like slightly off center, I'm like, I just have to start over again. Which is nice, because like, for these, for example, I just like peel the vinyl off and like clean it and like put new vinyl.
3.1	Creations	Discussion on a specific project that one has made or how one went about making that project.	Code when participant says something like "I made this." This code is meant to capture all of the projects that a participant has made because the participant most likely does not go into detail on every project that they have made. Therefore, this code captures that they learned how to make "a hat rack," "a 3D printed keychain," "a logo," etc.	I had an English class where we -- it was like based on the 1800s, like power and stuff, and so I had to make medals. Like a commemorative coin that we had to laser cut them out of wood. So my team made this probably 6 by 6 on both sides. It turned out really nice.
3.2	Mechanisms	Discussion on explaining the mechanisms of one's project and how the project works.	Code when participant describes the details of a design, how it works to achieve a designated task, and how the parts/pieces work together in the design. Code accompanies the participant describing, "This is a project that I made and this is how it works."	So then the inside -- as this rolled, this could freely move against your muscle which is like there's a notch in the middle so that would notch into here, if that makes sense, because this is two parts. We just superglued them together.

ID	CODE	Definition	Coding Rules	Examples
4	**DESIGN TERMINOLOGY**	Discussion using words, phrases, or language that are particular to the design or making activities.	Code when participant uses jargon such as "STL file," "raster," "bitmap," "dowel," "lock and key," etc. that are characteristic in the making of a design and using the design equipment. This code highlights the word, phrase, or language that is specific to the design tools and activities.	It's super-useful to know the difference between like bitmap and vector images.

ID	CODE	Definition	Coding Rules	Examples
5	**DESIGN TOOLS**	Discussion on the tools (physical and conceptual), mediums, means, or equipment that is used in order to create something; knowing how to use the tool when to use the tool or how the tool works.	Code when participant describes the devices and materials that they use and have learned about. This code does not look at depth of their understanding, but is associated with developing and acquiring more experience with design techniques, machines, software, and materials. *This code can by itself or used to encompass multiple of the codes below. For example, a participant might describe their understanding of the machine, software, and material in a scenario that is too difficult to create distinctions, which would allow for the code 'design tools.'*	And then we also have them laser cut, which is -- helps them think in the same way of -- like if I -- this would be horrible, but if I wanted to make this using laser-cuttable material, the most you can laser cut is about 1/4 of an inch, comfortably, without burning your product, right.
5.1	Techniques	Discussion on conceptual techniques or tools that are used to perform a task.	Code when participant talks about the non-physical means that they use to accomplish a task or to further help them to complete a project. Examples include marketing, branding, interviewing, presenting, reporting.	And they wanted texture to be inspired by your brand, but these lines didn't make as much as sense for a curved object or for putting the kind of technology in it that I needed to and the way it was going to be interacted with and having these indents, that had technology embedded in them made much more sense. And it just made a smoother process.
5.2	Machines	Discussion on the physical tools, machines, devices, or apparatuses that perform a task.	Code when participant points the tools or machines that they use or have learned about. This code is to capture the participant's knowledge about the physical tools and machines. Machines such as the "3D printer," "laser cutter," "vinyl cutter," "hammer," "chisel," "bandsaw," etc. The participant needs to explain their understanding of a machine for this code to be applied.	Like, for example, laser cutter, if you don't turn on that fan, like, one, it will likely ruin your project, because there's like a lot of dust and debris in there, and then two, it'll make the whole lab smoke up and stink, which is like not supposed to happen.
5.3	Software	Discussion on computer based software that are used to perform a task.	Code when participant uses a computer software, such as "Inkscape," "Solidworks," "Fusion," "Sketchup," or "Matlab." This code could be seen with 5.2 and 5.4 when the participant describes a project that they are making.	And, then once we had our design, we had to CAD it in Solidworks, Inventure, anything you want. I ended up using Solidworks…
5.4	Material	Discussion on the materials that are used in a design, such as understanding of the material's properties.	Code when participant reveals their knowledge about the material choices and properties, like when they give reasons to use one material over another, just say "this material is flexible," or describe the filament properties of a 3D printer.	Sewing is a little different since your material is so flexible, you have to kind of be aware of how the material is going to all come together. --- If you do that, you're probably going to want to use these kinds of metals.

ID	CODE	Definition	Coding Rules	Examples
6	**DESIGN PROCESS** ***Problem Solving Process*** ***Design Thinking Process***	Discussion on the process to design, problem solve, or incorporate design thinking strategies.	Code when participant broadly goes over their process for a design, their way to solve a problem, or their use of design thinking. A participant can say "It's just like problem solving" or "this is how design is" which means that they are referring to this code. *This code can be by itself or paired with the codes below.*	I enjoy the process of having a problem and like being able to solve it through being like this is the list of the possible outcomes that I think are why this problem is occurring. Let me tick of the boxes of like oh.
6.1	Acquaint and Ideate	Discussion on the first stage of the design process, which is conceptual and focuses on acquainting oneself with the task, goal, or problem space and coming up with ideas.	Code when participant describes collecting information about what they are trying to do, trying to understand the problem or goal, and producing potential ideas to solve the problem or achieve the goal. While the act of acquainting oneself with the problem/goal versus ideating may be describe in separate encounters, the two actions may greatly overlap; for example, a participant may ask "what are you trying to do?" and follow immediately with "well, have you tried this?" Use this code for when both acquaint and ideate occur together or when one does not appear with the other. This code often appears in question and solution form.	"What's your problem?" And then someone will be like, "Oh, I need to build a box." -- Okay, so what we did was we came up with a bunch of ideas. It was like a session where you're like nothing is a -- like don't say no.
6.2	Model and Refine	Discussion on the second stage of the design process where the design is modelled, built, prototyped, tested, refined/fixed.	Code when participant points to modelling ideas (whether on paper, virtually, or physically), and when describing the process for refining a design (whether through testing, making design changes, or fixing the design). Words used are "prototype," "sketching," "model," "iterate," "fix," "test," or "change."	And then realizing that two 45-degree angles come together to make a 90-degree angle. So it was like that was such a dumb thing that we should have realized. But doing that and be like, "Oh, okay, visually I understand how this works now."

ID	CODE	Definition	Coding Rules	Examples
7	**DESIGN INTUITION**	Discussion on knowing, recognizing, or being cognizant of the situation one is in, specific to design.	Code when participant shares an understanding of there are strategies, resources, and barriers that all have to be taken into consideration when creating a design. The world offers connections to design and here, this code captures when the participant makes those connections. *This code encompasses the codes below.*	The thing with the topic of health is so big that it was so much easier to pick one thing-- like, the faster you can narrow down what you were doing, the more energy you could focus on what your final project was going to be.
7.1	Resourcefulness	Discussion on using available resources and finding clever, strategic ways to achieve a goal or complete a task.	Code when participant talks about using what they have to make something, talking to someone else more knowledgeable, or Googling something. Words that may clue this code are "strategy," "resources," or "efficient."	Let me think what I can do with what I have.
7.2	Transferability	Discussion on transferring knowledge or ideas between domains; using ideas inspired by seeing someone else's work or seeing something else, or using one's design skills in other ways.	Code when participant discusses observing or participating in activities outside of the makerspace or outside of their project that relate to design. For example, when the participant talks about research, or a story of an encounter with a friend and how that inspired a project. To distinct from code 2.1, observing is one when one is watching for the clear purpose of trying to learn how to use equipment or make something and transferability has more to do with inspiration from seeing what others are doing.	So that's how I like have used the ways I design stuff for research as well. And that's what I like about design and apply it to research. And they're like, "Oh, how can I apply your knowledge to what I'm doing?"
7.3	Limitations	Discussion on the limitations, barriers, or obstacles of the individual or the space.	Code when participant uses the word "can't" or says things like "I couldn't do this because" or "I didn't know how to do it," If a participant says something like "because I only know 3D printing then I can't do anything else" then that is a limitation. If a participant says something like "because they only know 3D printing then they can't do anything else" then that is code 9.4 (extrospective) because it is about a body of people. Whereas, "Capstone students have to wait in line because there is only one waterjet" is a limitation of the space having only one waterjet.	And it was hell. It was that was like, everyone was at shop, like, making all their foam models very, very late, and it was partially like, I didn't really understand branding. And there was also, like, miscommunication about whether or not the object had to be functional.

ID	CODE	Definition	Coding Rules	Examples
8	**MAKERSPACES**	Discussion on learning about makerspaces and what all a makerspace entails.	Code when participant reports on the makerspace and what they know about the way the makerspace functions and what it is like to be in the makerspace. *This code can be by itself or paired with the codes below.*	I think I would talk about mainly the privacy aspect of it. Because it's -- like honestly, like I cannot highlight enough that that's my favorite like, one, the fact that you can go like anytime once you're like trained.
8.1	Access	Discussion on the ability to access the different aspects to a makerspace.	Code when participant describes what is available for them to use, what they may or may not have access to, and what the potential procedures are to gain access. Or, if the participant doesn't know what is accessible and available, this is equally important to code.	...because I don't have access to this lab for the purpose of a class or a research. It's just me using it as like a personal benefit, I guess. Because like I would not have known this existed if it weren't for like my friends
8.2	Culture	Discussion on the nuances of the culture, the roles, rules, and structure of the makerspace.	Code when participant talks about the different people who are a part of the makerspace (e.g., student workers, users), what it is like to be in the space, how the people act, what are the implicit and explicit rules that one is to follow. "It's just known that people who are doing school projects get precedence" or "you have to show your ID in order to get in" are examples of phrases that you might see. A participant also might use "environment" or "atmosphere" to actually refer to the culture. Note: culture can vary between makerspaces, and can also even contradict in a single makerspace - as in "there are pricks in the space" and "people are willing to talk to you"	I don't know if that makes sense, but yeah. It's really crazy like weekday afternoons and stuff, but the rest of the time is deserted.
8.3	Environment	Discussion on the physical space, layout, and design of the makerspace.	Code when participant points to the <u>physical</u> aspects of the space, the layout, the rooms, the "sounds", and the smells. Unlike 8.2, the environment code focuses on the <u>physical space</u>.	I feel like they're just set up differently. Like, when you go to [ME space], when I walk in, it's got, like a area for soldering circuits, make functional circuits, and an area for, like, poprivets and mechanisms to make functional mechanisms. But when you walk into the [ID space], you see sanders for getting things perfectly smooth, and a drimmel tool for getting things the perfect shape. You know?
8.4	Management	Discussion on how to maintain, cultivate, sustain, and manage a makerspace.	Code when participant uses words of "safety", "maintenance," "event planning," "workshops," "spreading awareness," "networking," "meeting", etc. in order to describe what goes into keeping a makerspace functioning and thriving. Management is an advanced type of knowledge that is predicated on knowing and creating the culture of the makerspace. Management is a leadership form of knowledge creation, whereas culture (8.2) is a socializing experience. This code may also refer to rules and roles put in place for better management of the space.	So, I was called the mentor lead when I was there, but now that's what a president does. And, then the - there used to be - we didn't have anyone for internal communication, so I just ended up doing that. And, then I - I think our safety lead was like really overworked. So like we put our safe - we like split that - that one up.

ID	CODE	Definition	Coding Rules	Examples
9	**ATTRIBUTES**	Discussion on the characteristics or attributes that one has learned, gained, or practiced.	Code when participant conveys an intrapersonal understanding of themselves or the makerspace, or the participant simply describes a scenario that showcase their growth, motivation, and developing of character	Or someone will walk by see me spending three hours sanding something be like, "What are you making? Like why are you spending so much time on this?" I'm like, "Well, I'm making this. And it's super-cool," and I talk about it.
9.1	Self-esteem	Discussion on one's level of confidence in a situation or the pride that they receive from making something.	Code when participant points to being "confident, "validated," "proud," "accomplished," or "feeling good."	And then this was our final product that we made. Dude, pretty sick, yeah. -- - So, it's like, I don't know, it really fills you up with a lot of confidence.
9.2	Self-knowledge	Discussion on understanding oneself through recognizing one's fears/emotions, or understanding one's likes, dislikes, passions, and values.	Code when participant mentions an aspect to themself or reflects on themself, such as "I've learned that about myself," or what the participant "like" or "dislike" or "am passionate about." This code also occurs when the participant talks about being "afraid" or having "fear." If the participant talks about acting to overcome that emotion of fear or frustration, etc. then that falls under code 9.3. Also, there may be times when someone's self-knowledge is a limitation 7.3 ("I'm a person who cannot focus") or a self-improvement 9.3 ("I have become very motivated and patient").	And I just like -- once I get my material, I like to stick to it. So like, I love acrylic, and I love vinyl. So I don't like laser cutting wood. -- - I'm very frustrated at it, my perspective is not going to help me at that point, because I'm frustrated, and I just need to take a step back.
9.3	Self-improvement *Strength of Character*	Discussion on the strengths that one has developed through making and makerspaces, such as becoming more patient, resilient, motivated, proactive, committed, perseverant, enthusiastic.	Code when participant describes active response of enduring through a situation, having motivation, taking a step back, overcoming unwanted emotions, coming back from a bad situation, following through and sticking with a task, or "just doing it." This code can be explicit ("I learned that I had to be patient") or implicit ("It takes time to make things"). In order to self-improve, one is to show patience, etc. through their actions.	But I wasn't careful with the painter's tape on the corners, and so the paint kind of like bled through. And I was like, "Okay, so if I'm going to be painting at this angle, I need to be more careful about the way I'm painting it. I need to like spray paint in a different way." And I had someone like teach me to use spray paint while I was there.
9.4	Extrospective	Discussion on one's awareness of things external to self, through being perceptive and gaining perspective about the totality of a group of people or the makerspace or opportunities.	Code when participant talks about what they realized about learning or about makerspaces because of what they have seen or experienced. This code can appear with "I didn't realize", "based on what I've seen", or "I've learned that." Also, the code lends to tangents, stories, or deep insights about what is outside of the person. This code takes a reflective stance. Such as, "they only know how to 3D print, so that can't do anything else."	It's - it's just a thing. I don't know, but it's just a thing. And, I've noticed that in all Makers Spaces. Like, I've talked to people in the [ME space] - same with them. They'll spend more time in making something that's pretty than just making it functional.

APPENDIX H. **PARTICIPANT EXCERPTS FOR *OPENING DOORS***

P1	So, like, if I hadn't played in makerspaces and, like, been exposed to, like, cool people doing cool things and, like, seeing other people's passion and then finding my own, I wouldn't know that, like, design is a thing I could do.
P2	I'm more willing to go for tools I don't know, because I've realized how simple it is to -- like, a lot of the tools, like – I never would have thought I would know how to use a laser cutter.
P3	I also feel like if I hadn't had [my friend] to, like, open my eyes, to be, like, "You can use this for, like, your hobbies and all that." That I would have thought it was strictly more like a utility school thing, versus, like, you know, make art out of this, or, like, you know, use it for your hobbies and stuff like that.
P4	I now describe myself as a designer and a problem solver, which I think I might have been before, but not in a refined way. Like I didn't understand my process. Like now I understand like, oh, empathy, empathized, defined, like prototype, test, roll out, like get feedback. And that's just like I did that so loosely before, but like now that I understand it as a process, I'm able to do it better. So I feel like industrial design, by putting me in these half tangible, half conceptual places, it's taking my craft and what I learned from my craft and making it a more refined process so that I can be a better problem solver. But I realize now it's so much about space.
P5	Making things helps. Because it takes your mind off. Because you go into like an overdrive zone, because you don't really have a lot of time, but you still have to get something out in that time so you're like not focusing on anything else. It really does help, but yeah. … I actually didn’t realize how much went into me coming to this point, with like, coming to Makerspaces.
P6	Having access to the [Makerspace] and just it being such a big part of my life definitely impacts the way I think about pretty much everything because I never really think about stuff as too hard, I guess.
P7	[The Makerspace] help me actually find that self-confidence, which makes me a more successful person because I trust myself more overall. I didn't know about this until now, now I'm thinking. Oh, shoot. Didn't know about that.
P8	And sometimes you, you know, I think there's a lot to gain from being in a position to teach others and also say, I don't know, you know. I think a lot of times I want to have the answer for people all the time, I'm a fixer by nature, which is why I love this job. So being able to say, “I don't know, let me get back to you,” has been a really important thing for me to develop and a lot of that's come from working in the shop. And then I would

	say the way it's encouraged me to both think critically and think bigger is been really important just for like how I approach problems, has been really cool.
P9	Definitely gives me a lot more confidence. And it makes me feel more comfortable about really working on any projects I have. And also knowing that I can help other people learn is just great. Really gives me a lot of confidence and makes me feel good to know that I can help other people learn things, pass on my knowledge.
P10	But when I took over his shift he was the only person scheduled for that shift, so at that point I'd been in the wood room with other [student workers] at that point, like getting myself more comfortable with it, but that was the first time I was in there alone, and I was definitely nervous going into it, but then once I just got started in there it wasn't that bad. I found that I knew a lot more than I thought I did
P11	So like if there's like a device that have an idea of making, like I know how to make it, but I think that's like one of the most important things I've been taken away from learning how to build things here at [the Makerspace].
P12	You have to be able to ideate and realize the bigger picture in what you're building. If something is a better way to do it, then just go with that even though you had the bandsaw in mind.
P13	I think I've had so many experiences at [University] that I would have never ... like all the things I am most proud of that I did at [University] were because I used these makerspaces.
P14	Actually, I would say I'm introvert, meaning not very talkative. Not very easygoing. I think most engineers are. But then, have to work with someone else and try to help, which may be very short period of time that I was helping the users that come in the [Makerspace], I feel like it opened up myself to try to communicate.
P15	Certainly being more proactive, because, you know, there's really no excuse not to do something … And then, also, just figuring out how to communicate your problems, too. And just like, ... if you don't know how to do something, you need to explain exactly what you don't know how to do.
P16	I've made a lot of good friends and learned how to interact with people through these two things. Communication is key as an engineer. You've got to be strong in that. Being a [student worker], I'm exposing people with difficult problems, sometimes difficult customers, I know to work through those things. Definitely not my strong suit, but I think I've improved in that area. Mistakes and building things, 100% necessary going to a small bench top setup to whatever you want to scale up. Then just from a very technical level, just learning new skills. The laser cutter, 3D printer, and electric prototyping, all those things I got exposed to through those two activities. I guess that's a nutshell.

P17	There are going to be people that are going to be jerks. The way to overcome that is just to realize they're not worth your time. They're just ignorant. They probably have some internal, personal issues that they're projecting out onto you. It's really not your fault they're like that, and it's not your job to fix it.
P18	I realized that people had a lot of confidence in me. Like, if I think I should try to learn something, I can just do it. That's really sort of the turning point for when I started doing self-guided research, and relying less on other people.
P19	I think it's definitely made me like engineering a lot more. I think it's something I'm always gonna wanna do in my life. I was thinking about like once I leave college, how am I gonna make things? … Yeah, yeah. I've always ... liked hands-on stuff. Well I guess ... yeah, I kinda forgot about it for a while. But then especially the class I took last semester reminded me. Now I ... am really into it. So yeah.
P20	Everybody can be a good engineer if they work hard enough. It's about working your strengths. I should have realized that, if I didn't have the creativity, I had other strengths. … I was really trying to pay attention to everything that was around me and realized that engineering is everywhere and it's beautiful and it's functional. It matters, even if it's small.

APPENDIX I. **UNIVERSITY MAKERSPACES INTERVIEW PROTOCOL**

Interview Frame for Best Practice

Purposes:
1. Generate initial impressions of university maker space
2. Determine best practice of the maker space and possible suggestions for improvement

Format – (Interview)

- 1-4 Faculty/Staff
- Webex Meeting
- Recording (audio & video)
- Schedule for 1 hour

Introduction to the process for participants –

We are interested in how to improve upon and replicate the success of university maker spaces. Through this focus-group, we want to get your feedback from your experience with your university maker space, initial and general impressions, specific features and suggestions. This is not a formal discussion in which we will go around the room in a specific order –instead, please jump in at will. I will work to make sure that everyone has an opportunity to participate. If you have additional thoughts/ideas after this discussion has ended, please feel free to e-mail me (I will distribute business cards).

Question Outline

Theme 1: What is the culture of the space?

1. How did the makerspace get its start and how has it grown since?
2. How is the space supported now?
3. Who oversees or guides the space? (Professors; full, assistant, associate)
4. How is the space staffed and trained?
5. What are the benefits or compensation to the staff?

Theme 2: Who can access the space?

1. Approximately how many people use the space per year?
2. Who has access to the makerspace?
    a. Student

    b. Faculty
    c. Community
    d. Clubs
    e. Class
    f. Major
3. What classes or types of classes are integrated into the makerspace?
4. Is access to the space restricted in any form?
    a. Class only?
    b. Tool training?
5. When is the space open?
    a. What days and hours?
    b. Access linked to school/class schedule.

Theme 3: What is the makeup of the space?

1. What is the approximate size of the space?
2. How is the space distributed about campus?
3. What is the visibility of the space to other students?
4. What type of equipment is available?
    a. Wood Shop
    b. Metal Shop
    c. Electronics Shop
    d. Textile
    e. Rapid prototyping (3D printers, laser cutters, CNC)

Theme 4: What makes the space unique/successful?

1. What do you think makes your space successful?
2. What are the most innovative and important features of your space?

Theme 5: Other aspects of the space.

1. What is the approximate operating cost of your space?
2. How is safety handled?
3. What is the future vision of the space?
4. Would it be possible to get ahold of the current blueprint?

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